LASER TECH BRIEFS

Spring 1994
Vol. 2 No. 2

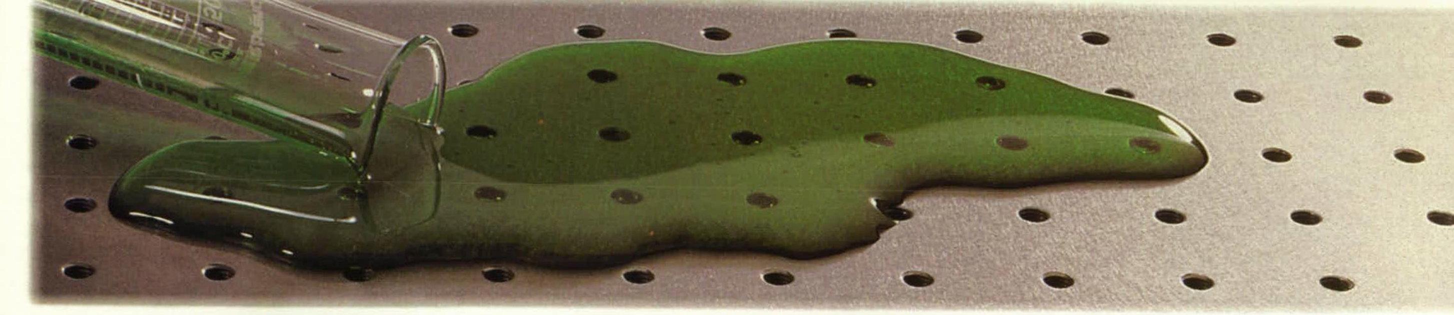
REPORTING THE LATEST PHOTONICS TECHNOLOGY FROM U.S. FEDERAL LABS

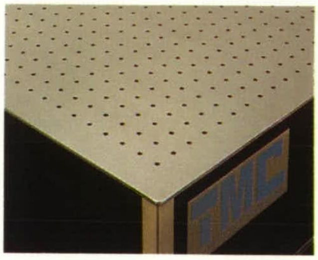
IN THIS ISSUE:

LABORATORY PROFILES OF

- ROME PHOTONICS CENTER/*GRIFFISS AFB*
- LASER HARDENED MATERIALS EVALUATION LAB/*WRIGHT-PATTERSON AFB*

LASERS • OPTICS • ELECTRO-OPTICS • FIBER OPTICS • IMAGING • INFRARED TECHNOLOGY





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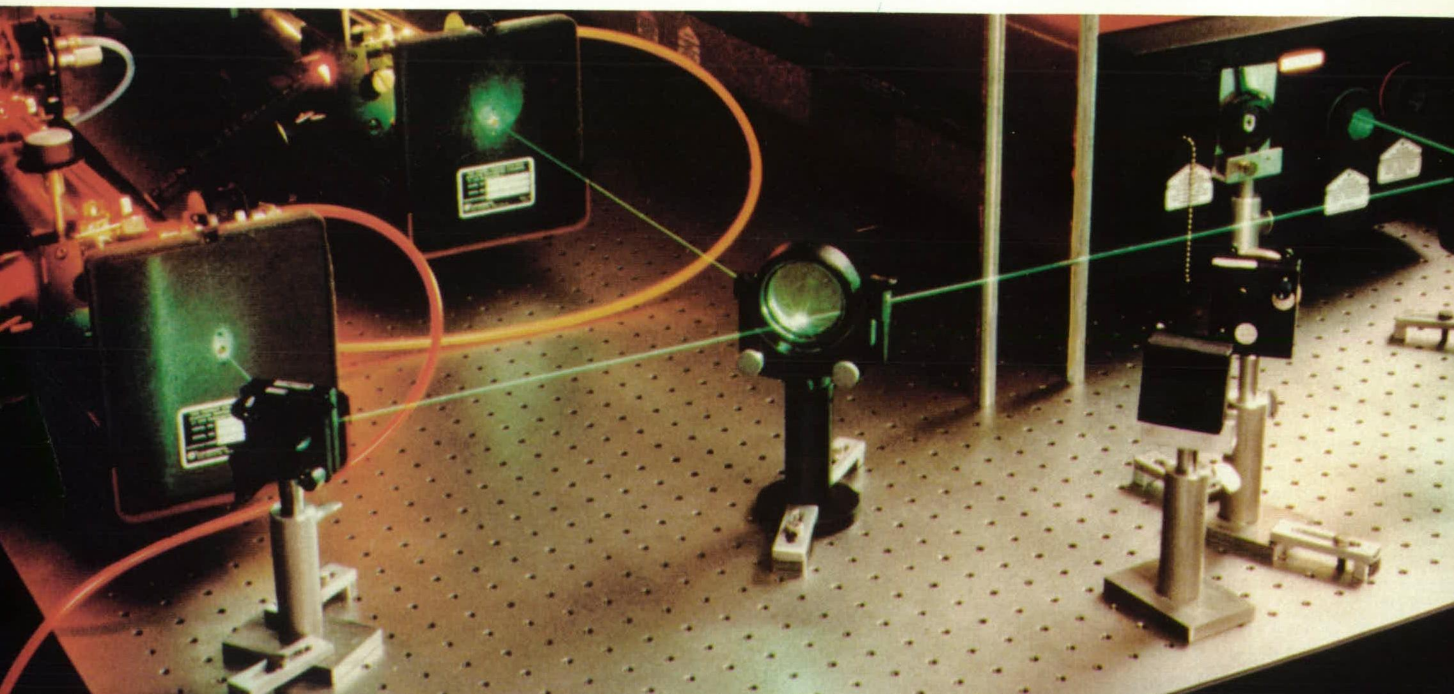

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SPRING 1994
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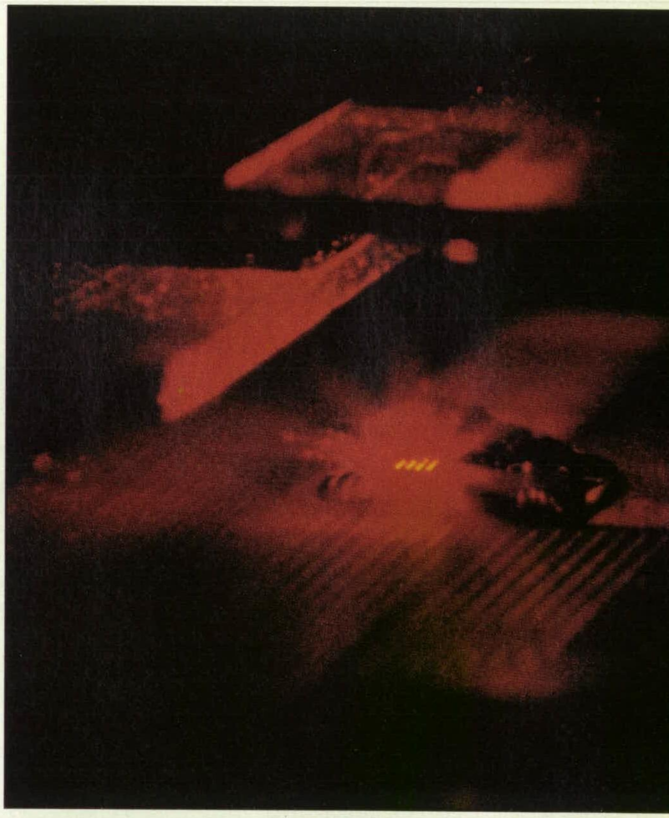
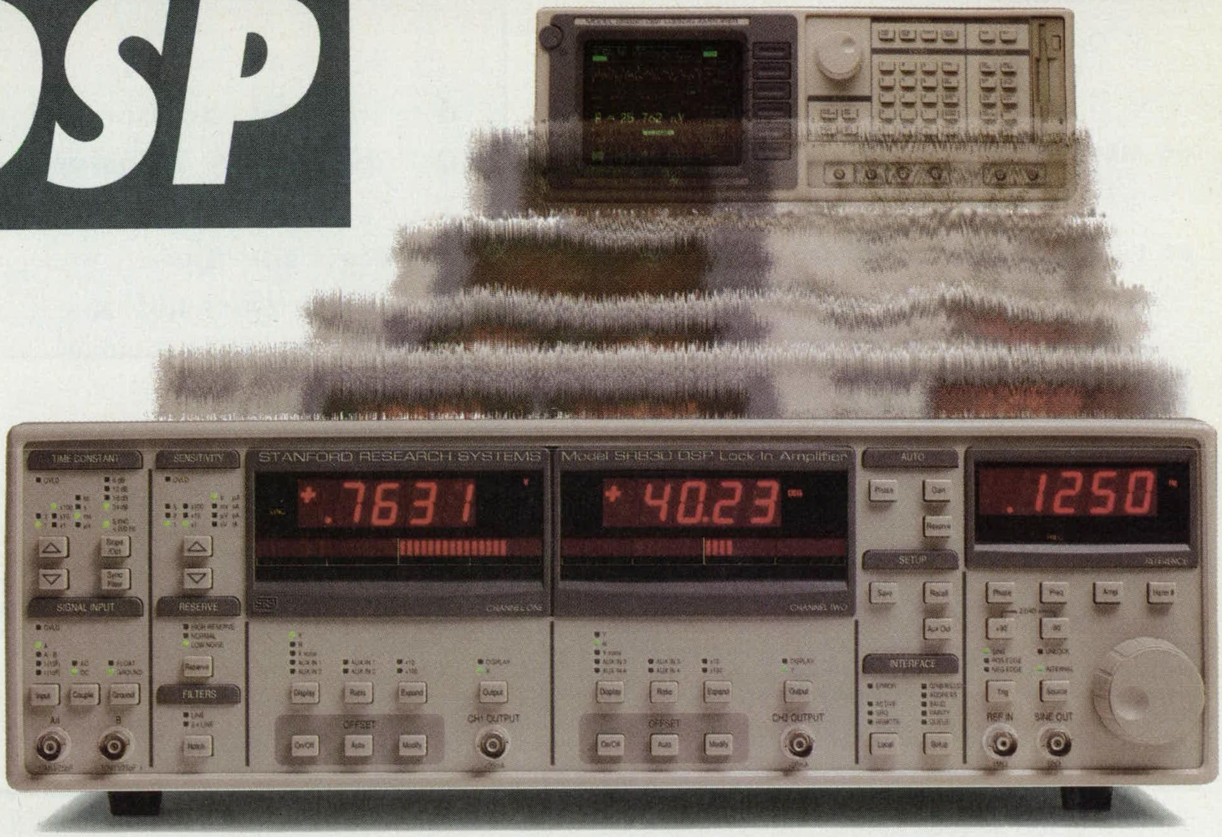


Three-dimensional optical interconnects allow the vertical integration of VLSI electronic layers in a multiplane configuration. Rome Laboratory's Photonics Center at Griffiss Air Force Base, NY, has demonstrated 3D optoelectronic computers based on holoplanar interconnect techniques, using proven silicon-based technology. In the photograph above, an LED array on the bottom layer transmits to a diffractive optical element above it, which redirects the light to a detector array on the third plane below it. See the brief on page 26. Photo courtesy Rome Laboratory.

(continued on page 4)

DSP Lock-In Amplifiers



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DEPARTMENTS

On The Cover:
One of two carbon dioxide laser systems designed, produced, and operated by the Materials Directorate for the Laser Hardened Materials Evaluation Laboratory at Wright-Patterson Air Force Base, OH. Photo courtesy Wright Laboratory. *See the article on page 12.*

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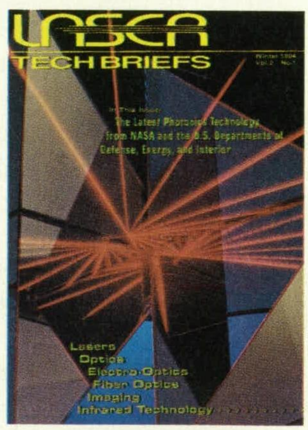

Shown above is the cover of the Winter 1994 issue, which inadvertently failed to provide information about the cover's subject and provenance. For the photographic interpretation of a laser-like light sculpture, pyramidal shapes of free-floating high-gloss reflective Mylar were configured so that illumination created laser-beam-like images. The photograph, kindly provided by DOE Brookhaven National Laboratory, Upton, NY, was taken by Mort Rosen, Brookhaven's Photo Department Supervisor. We regret the omission.

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EDITORIAL NOTEBOOK

Robert S. Clark
Editor

It is with a great deal of satisfaction that I point to some aspects of this Spring 1994 issue of *Laser Tech Briefs*, aspects that further stretch its editorial scope. The "Resource Report" on page 12 goes behind the scenes at the Laser Hardened Materials Evaluation Laboratory (LHMEL) at Wright-Patterson Air Force Base in Ohio, detailing unique capabilities that for the first time are being made available to the commercial world.

Until recently, LHMEL devoted its resources to national defense and the aerospace industry. But now LHMEL is offering a wide variety of companies the opportunity to use its facilities. These include the country's most powerful carbon dioxide laser, as well as a second CO_2 laser of lesser power, for heat and surface treatment. The lab can simulate a broad range of environmental conditions in its vacuum chambers, wind tunnels, and other equipment, and can do state-of-the-art diagnostics and data processing. Wright Laboratory's Materials Directorate foresees widespread use of the facilities in proof-of-concept and developmental applications. LHMEL should provide another example of the happy confluence of federal capacity with commercial need.

Also profiled in this issue is the far-reaching photonics research program of the Photonics Center at Rome Laboratory in New York State (see page 14). Several briefs detailing the cutting-edge work at the Center, from photonic systems to digital optical signal processing, are to be found in the technical sections. One of the most telling facts about the Center, however, is that the bulk of the work its staff directs is done off-site under contractual arrangements with industrial partners. The Center also cooperates with academic institutions and trade societies in an annual symposium on dual-use technologies. These are only a couple of the ways in which the Center manifests the growing synergy of the federal laboratory network with the commercial world.

Future issues of *Laser Tech Briefs* will probe such connections at other sites—governmental, academic, and industrial — as these once disparate worlds continue to come together in common endeavor.

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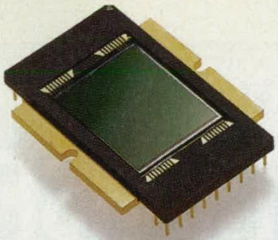

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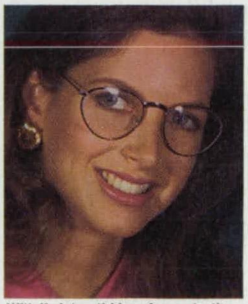

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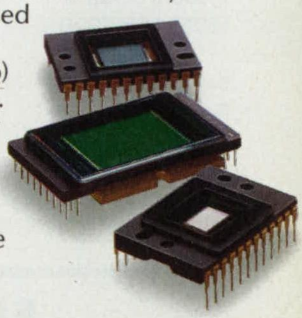

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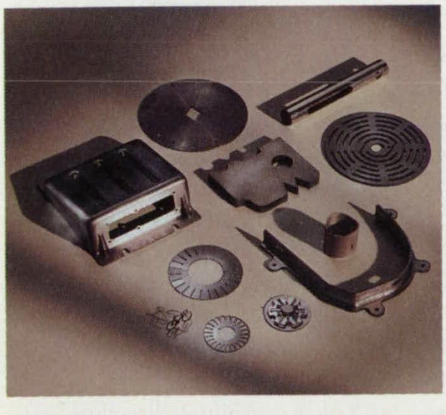

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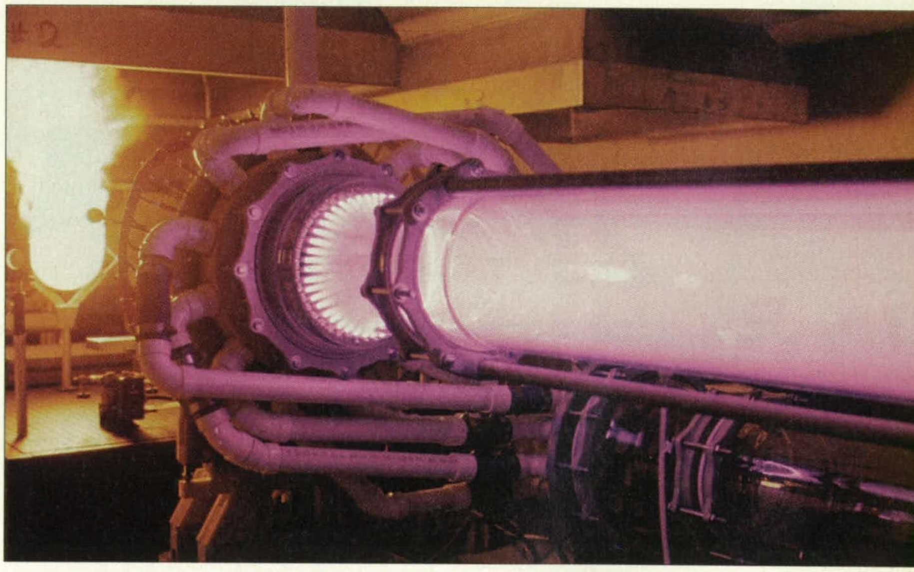
For the past seventeen years, the Laser Hardened Materials Evaluation Laboratory (LHMEL) at Wright-Patterson Air Force Base in Ohio has been testing and characterizing the properties of materials in support of national defense programs and the aerospace industry. Now, with the increased emphasis on technology transfer, this unique facility is opening its doors to the commercial world.

The focal points of this state-of-the-art laser test facility are two carbon dioxide laser systems designed, produced, and operated under the management of Wright Laboratory's Materials Directorate. The LHMEL I laser produces 15 kW of continuous-wave output power in a 9-cm-diameter beam. LHMEL II produces a 17-cm-diameter beam having 150 kW of CW output power. Stable, full-power irradiations using either laser can be maintained for durations of up to 100 seconds.

Both devices use a multimode resonator configuration, producing a flat-top spatial intensity distribution with an overall uniformity of ±12 percent. The beams of both can be focused down to 0.5 cm in diameter. The flat-top beam profile delivers a uniform quantity of energy to the sample, simplifying computer modeling and ensuring a controlled and repeatable laser exposure on target. LHMEL II also has an alternate resonator configuration, producing 30 kW CW or 15 kW average pulsed output power in a low-order Gaussian beam focusable to 100 μm.

Aimed at obtaining detailed materials characterization measurements under simulated environmental conditions, the LHMEL facility is equipped with vacuum chambers, wind tunnels, and mechanical loading equipment as well as extensive diagnostics and data-acquisition systems for the purpose of collecting and processing the response data.

Wright Laboratory officials believe that the unique capabilities and materials testing experience of this government-owned, contractor-operated facility will provide commercial users with unique opportunities. Commercial uses might include performing tests to demonstrate the feasibility of a new material processing technique before investing large amounts of capital in its development, verifying the high-temperature performance characteristics of a new ceramic component for automobile engines, doing a limited production run to laser-cut thick steel plates for a custom order, or using LHMEL's high power to perform deep-penetration welds of steel, aluminum, or titanium.



Wright Laboratory Materials Directorate's LHMEL II, the nation's most powerful CO_2 laser. Maximum intensity is rated at 3.4×10^6 W/cm^2 in CW multimode operation.

Heat/Surface Treatment to the Fore

LHMEL's capabilities are perhaps most beneficial to the commercial user in the areas of heat treatment or surface treatment of materials. High-temperature performance and wear resistance are top priorities for today's materials. Applications requiring irradiation of a large surface area to produce the ideal heat treatment for both strength and durability could be satisfied by LHMEL. Applying a focused laser beam to a rotating component in order to precision-harden the bearing races while leaving the bulk of the material ductile for higher strength and extended life could also be done using LHMEL. Other techniques to increase wear resistance, extend service life, increase operating temperatures, or even inhibit surface corrosion might be developed with the means available at LHMEL.

Its staff is confident that LHMEL's power levels, diagnostics, and data-acquisition capabilities make it an ideal facility for proof-of-concept testing in support of commercial R&D or process development activities. Tests are performed on a cost-reimbursement basis, or, if appropriate, a cooperative R&D agreement can be negotiated.

For a capabilities brochure write in 401 on the Reader Information Request card, or contact Rob Hull at Wright Laboratory Materials Directorate, Bldg. 651, 3005 P St., Ste. 1, Wright-Patterson Air Force Base, Ohio 45433-7702; (513) 255-2334, ext. 3165. ■

ROME LABORATORY'S PHOTONICS CENTER

A major research program draws scientists and industrial partners alike to a "superlab."

An aerial view of Griffiss Air Force Base in New York. Rome Laboratory is the larger of the two tan buildings to the left of the building with the peaked white roof at the center of the photograph.

From the outside, the Rome Laboratory Photonics Center at Griffiss Air Force Base is unprepossessing: it gives no hint that it houses one of the nation's most intensive photonics research and development efforts. Once inside, a visitor's perception changes, and it quickly becomes apparent why Rome is the Air Force's lead laboratory for optoelectronic investigation.

Rome Laboratory, of which the Photonics Center is just one constituent, is one of four Air Force "superlabs." Its charter directs activities toward the overall area of command, control, communications, and intelligence (C^3I). Part of the Air Force Systems Command's Electronics Systems Division, with headquarters at Hanscom Air Force Base near Boston, Rome encompasses four directorates: Intelligence and Reconnaissance, C^3, Electromagnetics and Reliability, and Surveillance and Photonics. Overall the Laboratory has a staff of about 1000 people at Rome, with another 200 located at Hanscom, and a budget close to $300 million.

Rome Lab grew out of the Watson Laboratory in Red Bank, NJ, where responsibility for radar and navigational technology development was lodged during the Second World War. In 1951 Congress closed Watson and moved the operation to what was dubbed the Rome Air Development Center (RADC) at Griffiss in central New York State. During the 1950s, Rome developed a wide range of radars for air and space surveillance, air traffic control, and early warning systems. Among its projects were the original Distant Early Warning system — the "DEW line," the first long-range surveillance phased-array radars, and the ground-target radar technology that enabled the Joint Surveillance and Target Attack Radar System (J-STARS) to track hundreds of armed vehicles simultaneously during the Persian Gulf conflict.

Concurrently with these efforts the lab began to focus attention on the potential of photonics to increase speed, reliability and capacity in information-gathering and communication. The Photonics Center was dedicated in 1987, and its first director, on sabbatical from the University of Rochester, was Dr. Ken Teegarden, a professor at, and former director of, Rochester's Institute of Optics. A turning point was the major renovation in 1989, an expansion and improvement of facilities that cost upwards of half a million dollars. The new Center, dedicated in October of that year, consumes 20,000 square feet of net space. Nine thousand square feet are devoted to lab space, about four times as much as when the lab first opened in 1987.

Currently about 50 people work in the Center. Capabilities include an ultrafast test lab, optical network testbed, and wafer testing and photonic microwave processing characterization equipment. There is no foundry; semiconductor materials

are provided by Cornell University and other sources. Associate Chief Scientist Brian Hendrickson has overall responsibility for activities at both Griffiss and Hanscom.

A TRIO OF RESEARCH DIRECTIONS

At present the Center's work takes three principal avenues. One is optical beam-forming for interface with phased-array antennas to enhance the performance of microwave and millimeter-wave surveillance and communications systems. A second is analog optical and lightwave signal processing to improve target recognition and electronic countermeasures and develop high-speed network technology. Finally, digital optical signal processing architectures, devices, and interconnection schemes are being examined for their potential in surveillance and C^3I. Branch chiefs are, respectively, Greg Zagar for photonic systems, Andy Pirich for analog and lightwave photonics, and Richard Michalak for digital photonics.

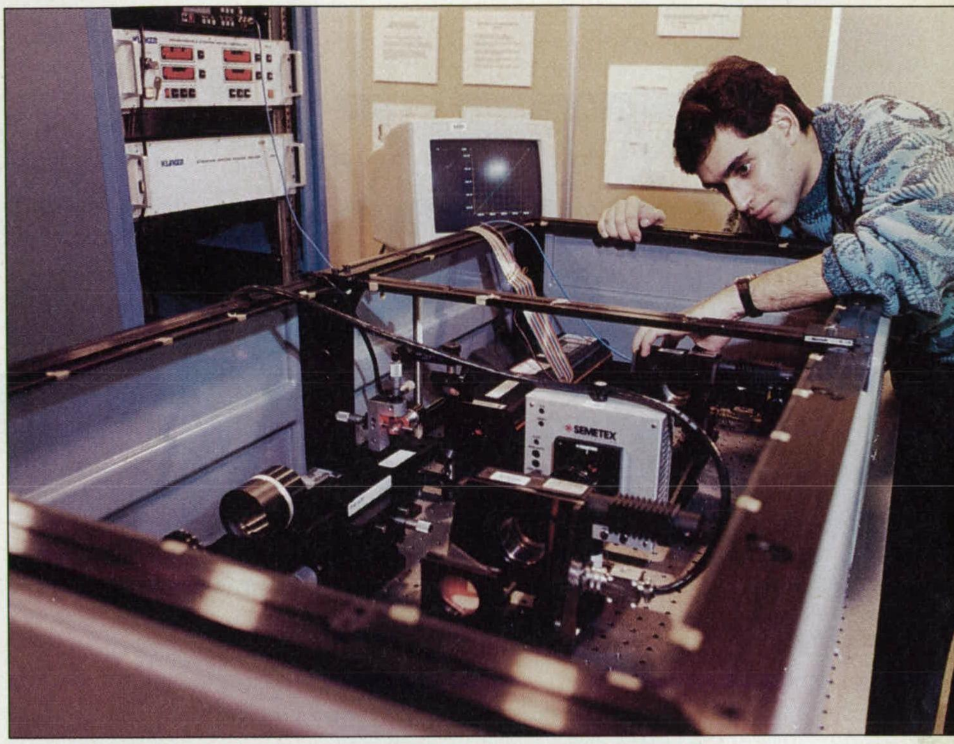
Rome Laboratory spends more than $30 million annually on photonics for a mix of programs, some in-house but the bulk of them outside contracts with industrial partners technically directed by lab engineers. Two programs that typify the Center's surveillance and communications thrust are carried out off-site. In Malibu, CA, Hughes Research Laboratories scientists are pursuing development of an L-band 96-element phased-array antenna that incorporates fiber optic remoting of RF and digital control signals as well as a true-time-delay beam-steering mechanism. True time delay is achieved by a combination of fiber optic and microwave stripline programmable delays. Similarly, in Dallas, TX, a Texas Instruments team developed a low-loss, low-cost integrated phosphorus-doped SiO_2-on-Si (PSG) waveguide optical routing switch for radar phase control.

Rome Laboratory boasts more cooperative research and development agreements than any other Air Force Lab.

Both of these programs received support from ARPA as well as Rome Laboratory.

In the second category, that of analog optical and lightwave processing, a typical program focuses on development of a binary phase-only filter optical correlator that could have applications in target identification as well as fingerprint and credit-card identification. Based on a de-sign patented by Dr. Joseph Horner of the Center, a team has built an optical correlator using the filter to evaluate and further develop the current technology for optical pattern recognition.

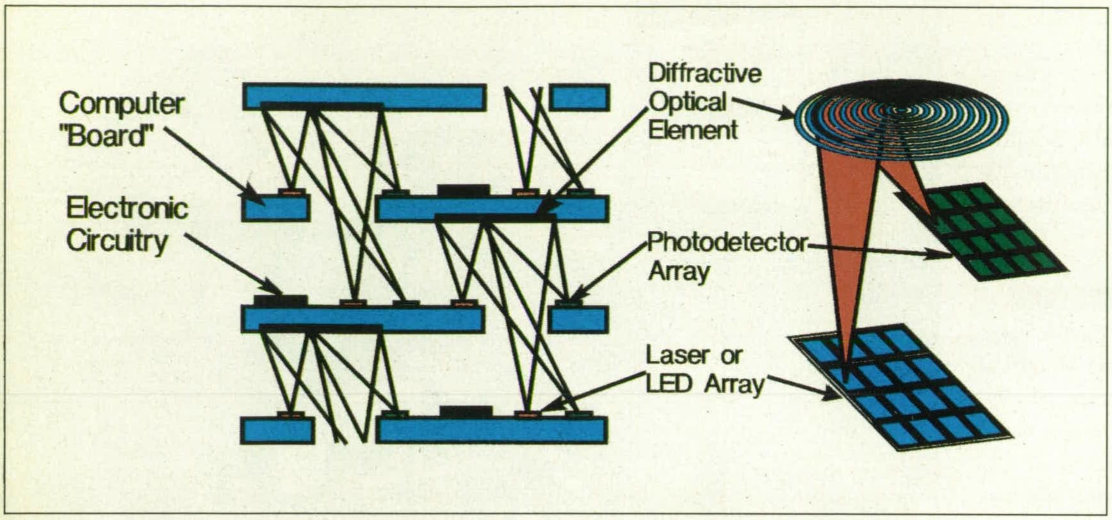
Correlation, a basic technique required in almost all pattern recognition systems, transforms image data in the spatial domain into a unique pattern in the frequency domain. In this case a lens inserted between the input and the filter does the transformation. Electronic systems must use specialized chips to handle the computationally intensive calculations, but optical systems using a binary phase-only filter can do two-dimensional correlations entirely in parallel without requiring specialized hardware and can handle more data at higher rates.



Researcher James Battiato aligns a spatial-light-modulator-based digital optical coprocessor. The device can perform high-speed off-line computations photonically for a laboratory PC.

Digital optical signal processing research at the Center has four main technical tracks: "smart pixels" for advanced optoelectronic processors, optical interconnects for optical memory interfacing, plane-to-plane optical interconnects for three-dimensional electronic signal processors, and computer-to-computer amplified optical crossbar interconnects.

In the smart pixel program, team members are integrating electronic logic with such advanced photonic devices as semiconductor laser gates, optical amplifiers, vertical-cavity surface-emitting lasers (VCSELs), and modulators. Planes of smart-pixel arrays interconnected via free-space optics are the means for digital signal processing and neural-network computing with ultrahigh throughput. Several contractual arrangements that aim to develop different types of VCSELs support the in-house effort to demonstrate a smart-pixel-based processor by 1996. Development of laser amplifiers, spontaneous-emission filters, laser logic gates, and laser memory elements has already taken place. The Center has integrated SEEDs, the self-electro-optic-effect device



Schematic representation of the three-dimensional optical interconnects under development at the Photonics Center. This work is the subject of a brief in the "Electronic Components and Circuits" section of this issue.

pioneered by AT&T, with FET neural net elements, and a supporting contractual effort integrated detectors with VCSEL logic elements.

The optical memory interconnect initiative strives to interface three-dimensional two-photon optical memory units, in support of a contractual program to develop optical memories. The collaborative effort is developing dynamic focusing lenses and 3D memory read/write schemes, to be combined in an optical memory interface demonstration system by 1997. The lab was among the early leaders in research on write-once read-many optical memory, and work continues on tungsten-oxide memory technology, and on 3D erasable organics that may prove capable of storing terabits per cubic centimeter. Other pursuits involve femtosecond optical sources, programmable PLZT grating structures, and thin-film optical switches.

In another aspect of developmental work, 3D optical processor interconnects are being evaluated as on-plane and free-space plane-to-plane links for stacked silicon wafer and stacked multichip-module signal processor architectures. A number of devices, including LEDs, VCSEL emitters, detectors and diffractive optical elements were fabricated in-house and under contract for these purposes. Polymer waveguides are also being investigated for clock distribution. Already demonstrated is a 16-channel, 10-MHz LED-based optical interconnect using ultralow-noise metal-semiconductor-metal silicon detectors.

In a collaborative research and development agreement with General Electric, the Center's photonic devices will be integrated into existing multichip module designs to demonstrate high-speed dense optical interconnects for signal processing. An associated contractual effort is investigating a self-routing holographic optical interconnect.

Finally, various optical crossbars are being developed for intra- and inter-computer connection. A novel VCSEL crossbar design is expected to deliver high-speed all-optical routing. Another contractual collaboration is developing an asynchronous transfer mode switch, and a SEED-based 2 X 2 switch has been fabricated. A related contractual agreement supports work on an integrated-optic amplified crossbar switch with a fiber optic interface. (Several of these developments are subjects of briefs in the "Electronic Components and Circuits" and "Electronic Systems" sections of this issue.)

A FOCUS ON BASIC RESEARCH

Complementary to the work at Griffiss, which concentrates on applications and systems integration, is that at Hanscom, which focuses on basic research in materials and devices. One significant program there is developing platinum silicide as a detecting element for future focal plane arrays. Another is the investigation of photorefractive materials that could be suitable for semiconductor amplifiers and optical filters.

Though the Laboratory's primary goals are closely related to the Air Force's present and future role — as one spokesman put it, "getting the rubber on the ramp" — it is also increasingly involved in technology transfer to the private sector. This month Rome will cooperate with the State University of New York Institute of Technology at Utica/Rome and the Mohawk Valley Section of the IEEE in sponsoring the fourth annual "Dual-Use Technologies and Applications Conference." More than 300 papers in 11 parallel sessions, including one on photonics, will underline the challenge of funneling emerging technologies into commercial applications.

Already Rome Laboratory boasts more cooperative research and development agreements (CRADAs) than any other Air Force Lab. In addition to Hughes Aircraft, GE, and Texas Instruments, mentioned above, the Center itself has collaborated with Martin Marietta, AT&T, and Corning.

Paralleling these efforts, the Center actively fosters cooperation with educational institutions. Visiting professors and researchers who have used the Center's facilities have come from Syracuse University, the University of Rochester, Rochester Institute of Technology, Cornell University, Princeton University, the University of Alabama, Georgia Institute of Technology, Rutgers University, and Stevens Institute of Technology, among others. Added to this is the "palace knight" program, in which the lab pays the educational expenses for top-grade Ph.D. students who are working in photonics-related research.

Not only in the front rank of developing tomorrow's advanced technologies, the Photonics Center appears to be setting the pace in getting the fruits of its labors out to the industrial and academic communities at large. ■

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CCD With a "Thin Gate"

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NASA's Jet Propulsion Laboratory, Pasadena, California

A silicon-based charge-coupled device (CCD) that uses a thin layer on polycrystaline silicon ("polysilicon," or "poly" for short) has been developed to enhance sensitivity to ultraviolet and soft x-ray photons. A conventional scientific CCD utilizes three relatively thick polysilicon gates in forming individual pixels (referred to as three-phase CCD technology). The thick gates absorb incoming photons, making the sensitivity very low within this wavelength range. For example, conventional poly gates with thicknesses ranging from 2,000 to 5,000 Å will absorb almost all incident ultraviolet photons (1,000 to 4,000 Å). To circumvent this problem, the CCD substrate can be thinned and the sensor backside illuminated to avoid frontside gate absorption. This process, however, is difficult to implement and is very costly.

Figure 1 illustrates a few pixels in one corner of a developmental thin-gate CCD, showing the thick poly gate layers 1, 2, and 3, plus the new thin gate. The width of the first three layers is reduced in size so that they only cover a fraction of a pixel, allowing photons to enter the fourth poly layer unimpeded.

Poly 3 (shown cross-hatched in Figure 1) is deposited on layers 1 and 2 and acts as a conductor to drive poly 4. Poly 4 is deposited over the entire array surface and makes contact with layer 3 through the contact opening shown. When layer 3 is electrically driven, it also

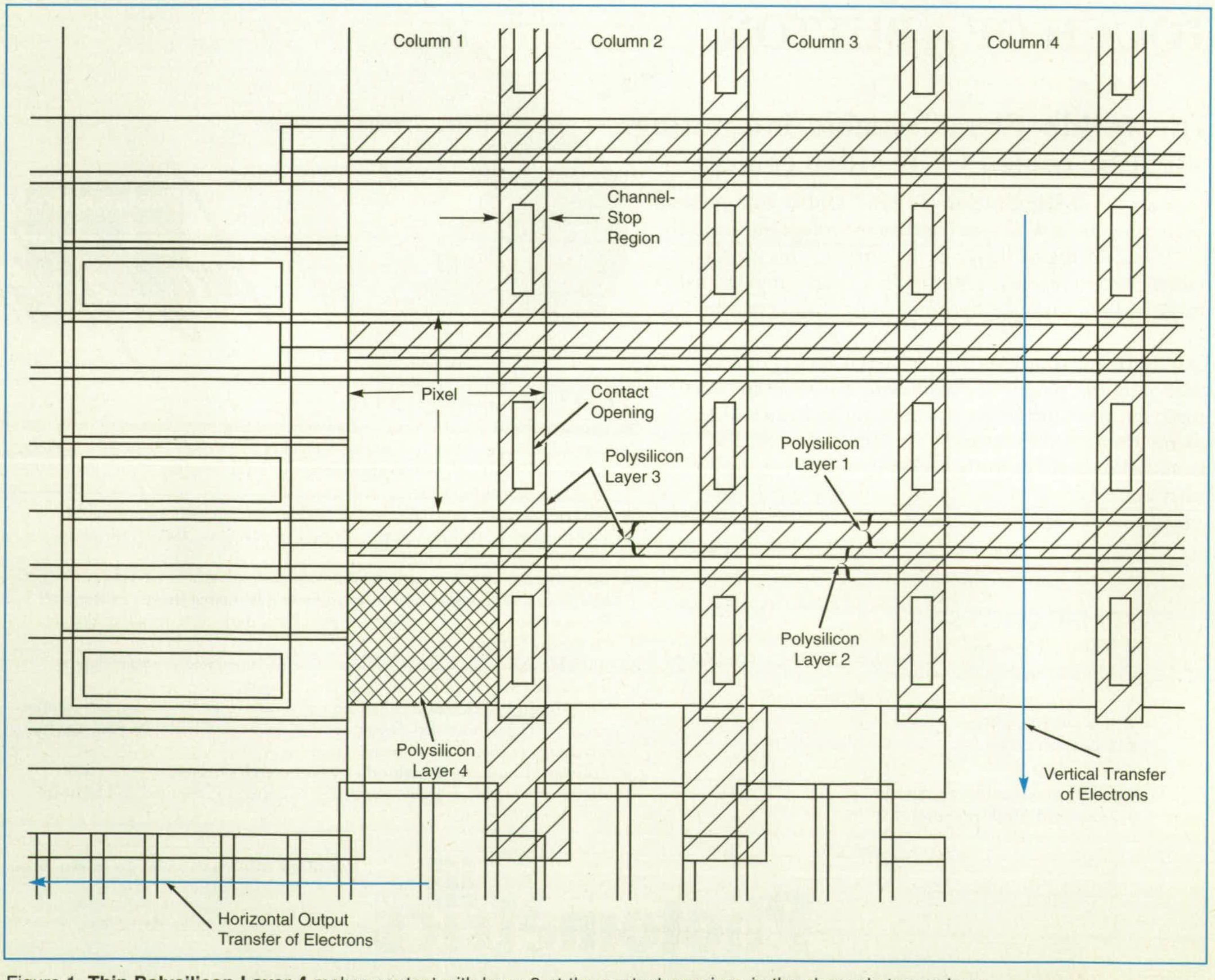

Figure 1. **Thin Polysilicon Layer 4** makes contact with layer 3 at the contact openings in the channel-stop regions.

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drives layer 4. Therefore, poly layers 1, 2, and 4 are used to collect and transfer charge as a conventional three-phase CCD would do.

The thickness of poly 4 can be varied to minimize the frontside "dead layer" to achieve the highest quantum efficiency possible. A thin-gate thickness of 400 Å has been implemented on two recent NASA CCD's for the CUBIC and MISR projects. An order of magnitude increase in sensitivity at 4,000 Å for the MISR CCD has been realized. Figure 2 shows an x-ray histogram generated by the 1,024 × 1,024 thin-gate CUBIC x-ray CCD. Normally, x-ray photons with energies less than 1 keV cannot be detected, again because of gate absorption. However, the new thin-gate CCD is the first CCD that has detected x-ray energies less than 100 eV.

The poly 3 contact openings shown in Figure 1 can be eliminated if poly 3 is not oxidized. In this case, poly 4 is immediately deposited onto poly 3 to make electrical contact. It is also possible to make layer 4 even thinner by using a conductor other than poly. A monolayer of platinum may be suitable for future thin-gate CCD's.

This work was done by James R. Janesick of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 146*** *on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

William T. Callaghan, Manager
Technology Commercialization
(M/S 79-23)
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Refer to NPO-18811, volume and number of this Laser Tech Briefs *issue, and the page number.*

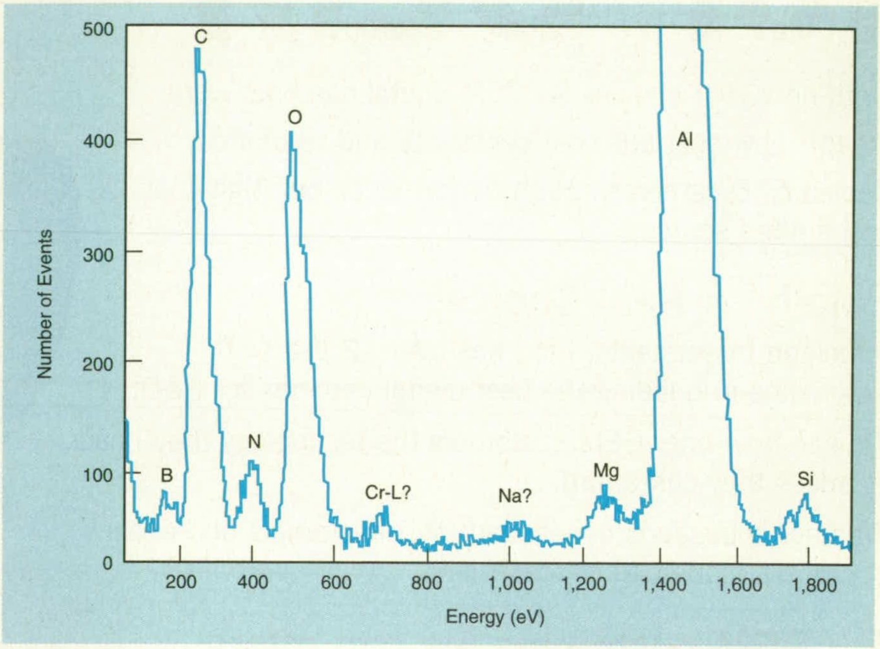
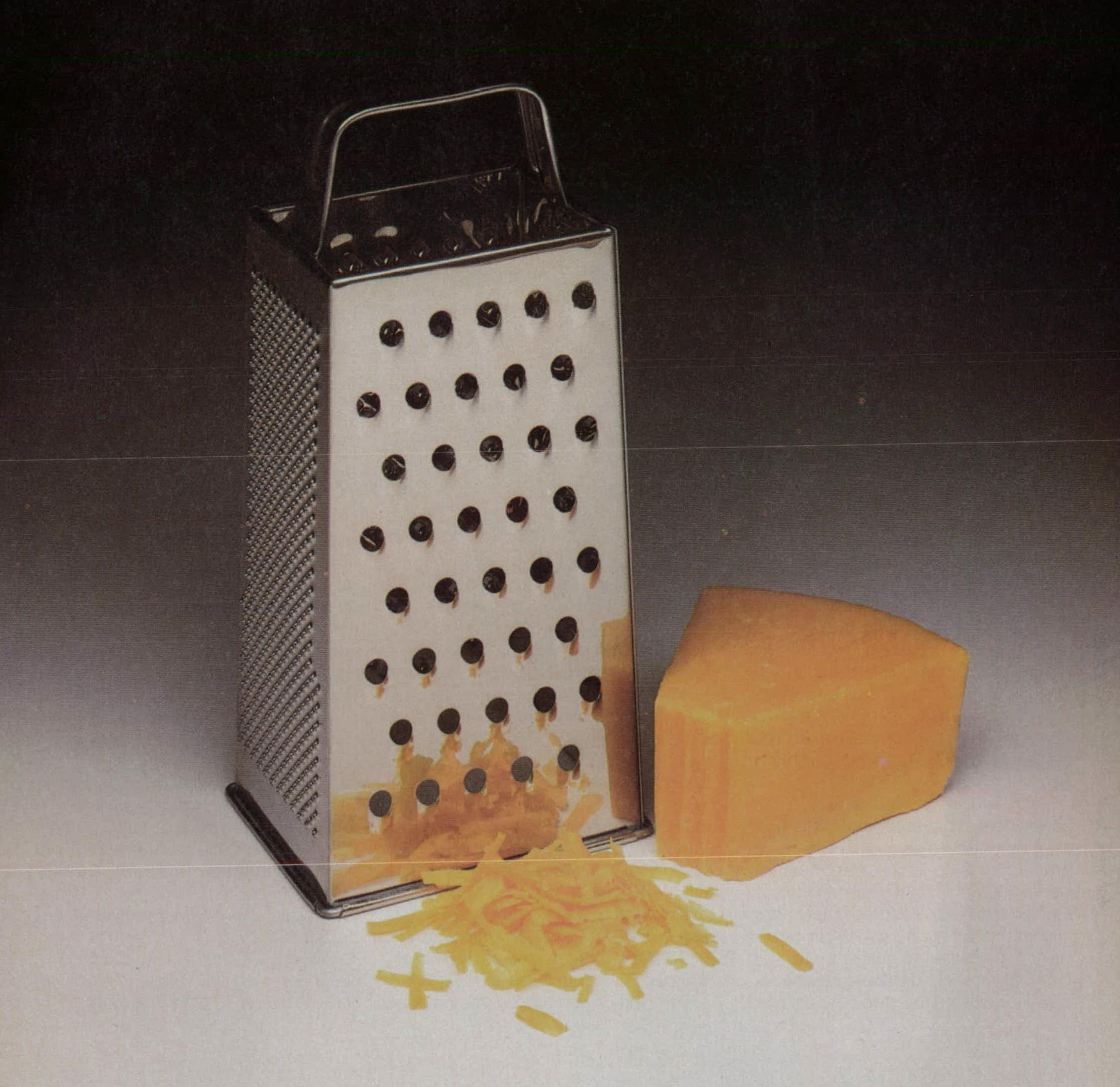


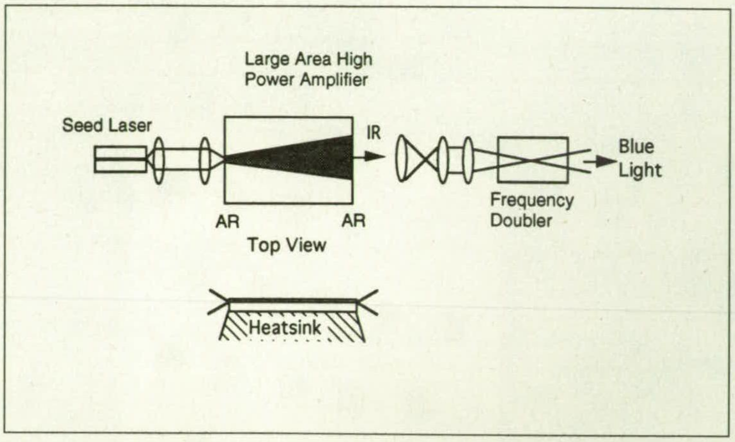
Figure 2. This **X-Ray Histogram** was generated by a 1,024 × 1,024-pixel thin-gate CCD.



Compact High-Power Infrared and Blue Light Sources

Multiwatt sources of coherent infrared radiation allow efficient blue-light second-harmonic generation.

Naval Research Laboratory, Washington, D.C.



High-power Source uses a large-area semiconductor amplifier and a low-power seed laser diode.

A new type of laser diode under development is capable of diffraction-limited emission in the multiwatt range. The emission power is an order of magnitude larger than other types of laser diodes, making these new highly efficient and compact sources attractive for numerous new applications. The infrared emission was frequency-doubled to generate blue light. Such an efficient and compact blue light source fills an important need in applications ranging from reprographics to optical data storage.

High-power diffraction-limited emission was achieved by using semiconductor amplifiers with large numerical apertures, as shown in the figure. The amplifiers were of a travelling-wave type, with reflection at both chip facets suppressed by an antireflection coating. Typical output aperture widths varied from 200 to 600 μm. A GaAlAs/GaAs single-quantum-well gain region was used, resulting in an emission wavelength of approximately 860 nm, with other wavelengths attainable by changes in the active layer's composition. A rectangular or tapered amplifier shape was used, the latter resulting in a better overall efficiency.

Amplifiers were seeded with a low-power signal from a conventional single-stripe laser diode, as shown. Diffraction-limited powers up to 5 W were measured from a 500-μm-wide amplifier aperture. In addition to diffraction-limited output beam quality, the high-power amplifiers can be intensity-modulated at gigahertz rates, and the emission spectrum duplicates the narrow linewidth of the single-mode seed laser diode.

Blue-light generation was accomplished by frequency-doubling the amplifier output in a nonlinear crystal. With CW operation, more than 50 mW of 430-nm radiation was generated. High-peak-power blue light pulses were also produced by mode-locking of an external cavity laser, using a large-area semiconductor amplifier gain element. Mode-locked output consisted of a 1-3-GHz train of pulses with an average power of 0.5 W, peak power of 13 W, pulse energy of 0.5 nJ, and pulsewidth down to 12 picoseconds. When frequency-doubled, the mode-locked source produced blue-light pulses with 1.6-W peak power, 8.5-picosecond duration, and an average power of 45 mW. Under mode-locked conditions, an overall average infrared-to-blue conversion efficiency of 10 percent was achieved.

The high-power infrared sources described here are compact, and have a long operating lifetime and a high electrical-to-optical conversion efficiency approaching 40 percent. They are well suited for numerous applications, including free-space optical communications, remote sensing, reprographics, and erbium fiber amplifier pumping. Amplifier-based blue light sources are very attractive for optical data storage, visual displays, medical diagnostics including flow cytometry, photolithography, laser confocal microscopy, and fluorescence excitation measurements.

This work was done by Lew Goldberg of the Optical Sciences Division, Code 5672, of the **Naval Research Laboratory**. *Inquiries concerning rights for the commercial use of this invention should be addressed to Dr. Richard H. Rein, Technology Transfer Office, Code 1004, Naval Research Laboratory, Washington, D.C. 20375-5320; (202) 767-3744.*

All-Optical, High-Contrast Multiple-Quantum-Well Asymmetric Reflection Modulator at 1.3 μm

Asymmetric Fabry-Perot structures yield high-contrast optical modulators.

Rome Laboratory, Photonics Center, Griffiss Air Force Base, New York

Asymmetric reflection modulators consist (see figure) of an asymmetric Fabry-Perot etalon formed by an optically nonlinear spacer between a low-reflectivity front mirror and a high-reflectivity back mirror. In the reflectance spectrum of a Fabry-Perot etalon, there is a minimum at resonance when the condition $m\lambda = 2n(\lambda)L$ is satisfied, where L is the spacer thickness, m is the order number, λ is the wavelength, and n(λ) is the wavelength-dependent refractive index. In a lossless asymmetric Fabry-Perot etalon, the reflectance at resonance will be nonzero due to the unequal front and back mirror reflectivities. However, when absorption is introduced into the spacer material, the reflectance goes to zero at the resonance wavelength when the condition $R_f = R_b\exp[-2\alpha(\lambda)L]$ is satisfied, where Rf and R_b are the front and back mirror reflectances, respectively, and α(λ) is the spacer material's absorption coefficient.

The asymmetric reflection modulator investigated consists of a 65 period 69 Å $Ga_{0.376}Al_{0.094}In_{0.53}As$ well/89 Å $Al_{0.48}In_{0.52}As$ barrier multiple-quantum-well (MQW) nonlinear spacer on top of a 24 period 936 Å $Ga_{0.3}Al_{0.18}In_{0.52}As$/1003 Å $Al_{0.48}In_{0.52}As$ quarter-wave stack back mirror. This structure was grown lattice-matched on a semi-insulating InP substrate by molecular beam epitaxy (MBE).

throughputs and low damage-threshold power levels that limit power and efficiency. In contrast, the design of this MOPA system takes advantage of both the high power of the Nd:YLF laser and the high efficiency of the laser diode. Potential uses of laser systems like this one include free-space optical communications, coded laser ranging, and generation of high-power, mode-locked pulses.

The construction of this laser system was made possible by the commercial development of the oscillator laser diode, the wavelength of the output of which can be tuned continuously from 1,042 nm to 1,053 nm by varying its temperature. In this laser system, the temperature of the oscillator laser diode is adjusted to maintain the wavelength at 1,047.7 ± 0.1 nm, matching the wavelength of the Nd:YLF laser. The characteristics of this laser diode include a wavelength-tuning coefficient of 0.3 nm/°C at constant drive current, a threshold current of 40 mA, a slope efficiency (change in output power ÷ change in drive current) of 0.32 mW/mA, and a maximum continuous-wave output power of over 50 mW at a drive current of 200 mA.

The amplifier is a commercial laser-diode-pumped, Nd:YLF, tightly-folded-resonator laser oscillator that has been modified into tightly-folded-amplifier configuration by replacing its output coupler with a coupling lens. Light is coupled into and out of the amplifier via a polarization-insensitive optical circulator, which is a three-port passive optical device. The light from the master oscillator enters the circulator via port 1, then leaves the circulator and enters the amplifier via port 2. After a double pass through the amplifier, the amplified light reenters the circulator via port 2 and finally leaves the circulator via port 3.

Figure 2 shows measured values of amplifier output power vs. input power (input power is defined here as that portion of the oscillator output power that reaches the entrance aperture of the amplifier). The maximum amplifier output power in the absence of modulation was 1,150 mW. The pump-diode drive current in the amplifier was 14 A, and the spontaneous-emission power measured at port 3 was 1.45 mW. The output laser beam was nearly diffraction limited.

The system was also tested with pulse modulation of the master oscillator (pulses of 1.54-ns duration, 6.18-ns period) while the oscillator drive current was biased at 100 mA and the oscillator temperature was maintained at 30°C. The average and peak output power of the system were 0.65 and 2 W, respectively; the power was limited by the available oscillator drive current. Neither wavelength chirp nor degradation of master-oscillator pulses was observed in the output.

This work was done by Anthony W. Yu, Michael A. Krainak, and Glenn L. Unger of **Goddard Space Flight Center**. *For further information,* ***write in 150*** *on the Reader Request Card.*
GSC-13588

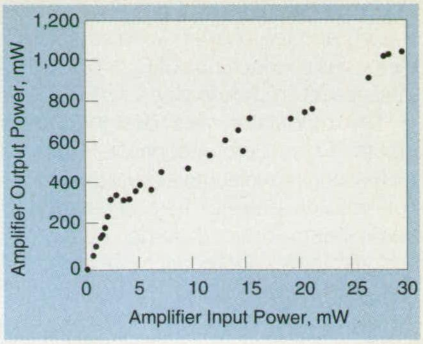


Figure 2. The **Power Gain** of the amplifier has a small-signal value of about 23 dB.

The etalon's front mirror is formed by the air/spacer interface and has a value of $R_f \approx 0.31$, and the quarter-wave stack back mirror has a reflectance of $R_b \approx 0.92$. The total spacer thickness was $L = 1.027$ µm.

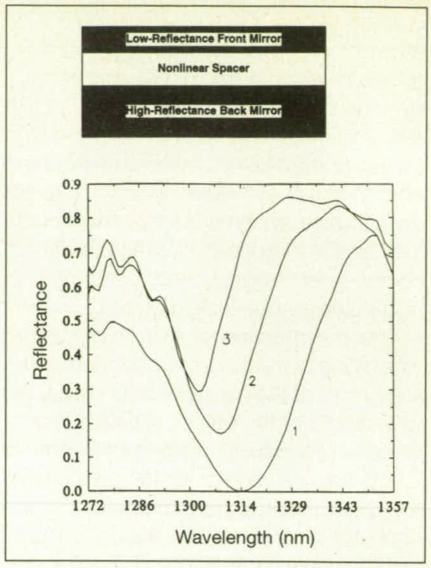
The modulator was designed such that the Fabry-Perot resonance is located on the long-wavelength side of the heavy-hole exciton peak to take advantage of pump-beam-induced large absorptive and refractive nonlinearities. In the absence of the pump, the absorption near the heavy-hole exciton is high and thus results in a balanced cavity and near zero reflectance at resonance. When the pump is present, the photo-generated electron and hole populations saturate the absorption near the heavy-hole exciton and result in an increase in the reflectance at resonance by unbalancing the Fabry-Perot cavity, *i.e.* $Rf \neq R_b \exp[-2\alpha(\lambda)L]$. There is also a considerable shift in the Fabry-Perot resonance due to the change in refractive index related by the Kramers-Kronig transformations to the pump induced absorption change.

The nonlinear behavior of the modulator was investigated in a pump/probe geometry. The nonlinear reflectance spectra at pump intensities of 0.0, 6.6, and 41 kW/cm^2 are shown in the figure. In the linear spectrum (no pump) shown by curve 1 in the figure, the minimum reflectance occurred at a wavelength of 1314.3 nm, with a value of 0.00055. As the pump intensity was increased to 41 kW/cm^2, the reflectance at the initial cavity resonance increased to a value of 0.7. As can be seen from curve 3, the increased reflectance is the result of the combined absorptive and refractive nonlinearities associated with saturating the heavy-hole exciton as indicated by the increase in reflectance and the shift of the resonance to shorter wavelengths. As can be seen in the figure, the reflectance rapidly increases from a value of 0.00055 at zero pump intensity to a value approaching 0.6 as the pump intensity is increased, corresponding to an on/off contrast ratio of 1090:1 and an insertion loss of 2.2 dB at a pump intensity of 30 kW/cm^2.

The wavelength dependence of the on/off contrast ratio for a pump intensity of 41 kW/cm^2 was calculated from the data in the figure. The relatively large operating bandwidth of the modulator is the result of the low finesse of the asymmetric Fabry-Perot cavity caused by the low-reflectivity front mirror. The modulator achieves an on/off contrast ratio of >100:1 over a 5-nm optical bandwidth.

In short, this was a demonstration of the first all-optical GaAlInAs/AlInAs MQW asymmetric reflection modulator for operation at 1.3 µm. The combination of high contrast ratio, low insertion loss and high speed make the modulator potentially useful in optical interconnect and communications applications where modulators and gates are needed to modulate and route low-energy (femtojoule) optical bit streams.

This work was the result of a collaborative research effort between M.F. Krol and R.K. Boncek of the **Rome Laboratory Photonics Center** *and T. Ohtsuki, G. Khitrova, B.P. McGinnis, H.M. Gibbs and N. Peyghambarian of the Optical Sciences Center at the University of Arizona. No further information is available.*



A simple schematic of an **asymmetric reflection modulator**. The **reflectance spectra** of the MBE-grown device are also shown.

Inquiries concerning rights for the commercial use of this technology should be addressed to Rome Laboratory, Office of the JA, Griffiss Air Force Base, NY 13441.

Fiber Optic Crossbar Switch

Fiber optic switching promises much for "data superhighway" applications.

Rome Laboratory, Photonics Center, Griffiss Air Force Base, New York

Fiber optics have been a part of telephone trunk lines, computer networks and specialized military communication and sensor systems for years. Fiber optics have also been shown to be very useful in aircraft applications such as "fly by fiber." Today, the technology is finding its way from myriad commercial, industrial and military applications to usage within the home. It will soon enable us to access incredible amount of information in microseconds. This information will have to be "switched," or redirected, in order to optimize a communication network or to establish a new interconnect path.

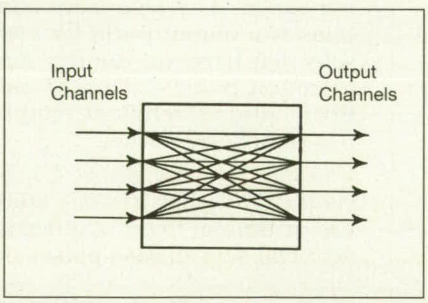


Figure 1. 4 X 4 **Optical Crossbar Switch.**

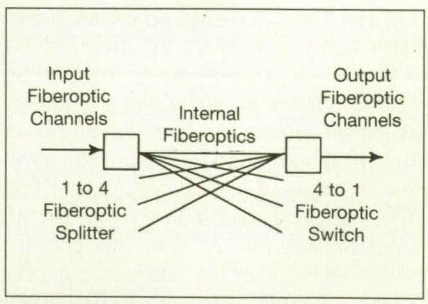


Figure 2. **Single-channel Switch.**

Switching in fiber optics is currently done using electronic switches that first convert the optical information to electrical signals, perform the required switching and then convert from electrical back to optical before the data is retransmitted. These data-form conversions and switching functions consume considerable time and power.

An optical crossbar switch is shown in Figure 1. Schematic details of the required hardware are shown in Figure 2. Optical crossbar switches allow the data, digital or analog, contained in an optical fiber to be switched without converting this information to an electronic signal. This maintains the signal integrity and high potential data rate of fiber optics while eliminating the need for electronic conversion components. Optical crossbar switches can switch any input port to any output port and can also broadcast any input port to two or more output ports.

The optical crossbar switch has a range of applications from controlling the communications of cable-television fiber

networks, as a "hub" controller in the commercial asynchronous transfer mode (ATM) data networks, as a trunk-line switch for telephone links, to a controller for data collected from "smart skin" sensors on board military or civilian aircraft.

This work was done by F. Haas and D. Honey of the **Rome Laboratory Photonics Center**, *Surveillance and Photonics Directorate, Griffiss Air Force Base, New York. No further information is available.*

Inquiries concerning rights for the commercial use of this technology should be addressed to Rome Laboratory, Office of the JA, Griffiss Air Force Base, NY 13441.

Neural Circuits Using F-SEEDs for Optical Processing

A SEED-based neural net combines the best features of optics and electronics.

Rome Laboratory, Photonics Center, Griffiss Air Force Base, New York

Field-effect transistors (FETs) monolithically integrated with self-electro-optic-effects devices (SEEDs) offer great flexibility for optical processing circuits. A new optical neuron is being developed for optical signal processing applications. Automated intelligence data classification schemes require digital computing and data storage resources beyond the state of the art. The computing and programming requirements can be reduced via the use of neural net architectures. Due to the high density and interconnectivity of large neural nets, optics can play a key role in communicating between planes of neurons. Integrated electronics and SEED-detectors or modulators allow the best features of electronics and optics to be used.

A block diagram of a neuron appears in Figure 1. The optical inputs I_1 are weighted by W_1 (also optical inputs) and summed. If the sum exceeds a threshold value T then the neuron fires and passes a logic 0 or 1 to other neurons. Thus the neuron implements the function $\Psi=H[\sum I_1 W_1 - T]$, where H is the Heavyside step function and Ψ is the output. The multiplication in Ψ is normally difficult to implement with conventional electronics. However, it can be easily performed in the SEED device by making use of the quantum confined Stark effect. The photocurrent J produced by the SEED due to incident optical power P is J=SP where S is the responsivity. Figure 2 shows the responsivity of the SEED (operated as a photodetector) as a function of reverse bias voltage. The responsivity increase by almost a factor of 3 for a 6-V change in bias. Thus P and S can represent the input I_1 and weight W_1, respectively, over that range.

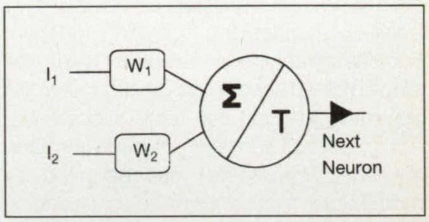


Figure 1. Functional diagram of a **Two-Input Optical Neuron**.

The complete prototype neuron ap-

pears in Figure 3. Optical power incident on SEED W_1 representing the weight is amplified to 4 or 5 V by the two integrated amplifiers and applied across the series combination of the SEED I_1 and the resistor. The voltage drop across the resistor is negligible. However, optical power incident on SEED I_1 produces small photocurrents that raise the potential on the gate of the FET to no more than 0.1 V. Thus the multiplication of I_1W_1 is relatively independent of the input power I_1. The box IM-2 represents another circuit similar to the Input and Multiply circuit IM-1 just discussed. The resistor combination at point Σ provides the summing function. For this prototype an amplifier takes the place of the thresholding function after the summing junction for testing purposes. After electrical summing of many in-plane neurons, SEEDs can also be used as modulators (not shown) to connect to other neural planes.

The work on SEED neurons is being done by M.A. Parker, S.I. Libby, J.S. Kimmet, P.D. Swanson, and R.J. Michalak at the Air Force Photonics Center, Surveillance and Photonics Directorate, **Rome Laboratory**, *Griffiss Air Force Base, New York. No further information is available.*

Inquiries concerning rights for the commercial use of this technology should be addressed to the Patent Counsel, RL/JA, Griffiss AFB, NY 13441.

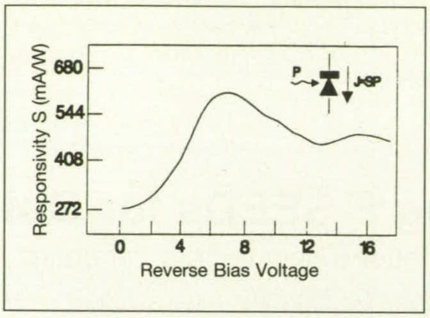


Figure 2. **Responsivity of the SEEDs** (after T.K. Woodward, "SEED Receivers and Transmitters," AT&T Bell Laboratories SEED Workshop, June 1993; and T.K. Woodward, A.L. Lentine, L.M. Chirovsky, S.S. Pei, J.M. Freund, L.A. D'Asaro, M.F. Focht, E.J. Laskowski, G.D. Guth, L.E. Smith, "Operating Characteristics of GaAs/AlGaAs FET-SEED Smart Pixels," Technical Digest, 1992 International Electron Device Meeting (IEDM), 655, Dec. 1992).

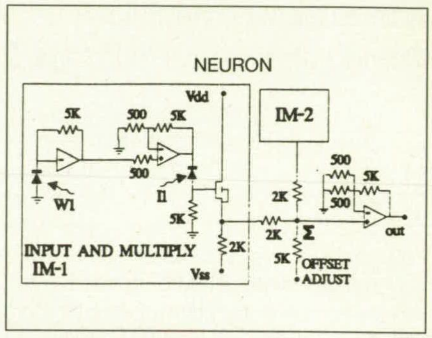


Figure 3: The **SEED Neuron**.

Three-Dimensional Computers Incorporate Optical Interconnects

Hardware implementations of technologies and capabilities meet the goals of 3D computing.

Rome Laboratory, Photonics Center, Griffiss Air Force Base, New York

Three dimensions can provide for alternative packaging of high-performance computers for a given volume. Structures that allow the vertical integration of several VLSI electronic layers in a multiplane configuration provide for systems where data flows not only along a single plane, as in a chip or board, but also vertically through many layers of electronics. The work described takes an evolutionary approach towards achieving these 3D structures by using proven silicon-based technology.

The use of silicon technology makes possible compatible optical modulators such as PLZT, ferroelectric liquid crystal (FLC), and plasmon light modulators integrated with an environmentally stable, constant optical power. Silicon detectors, either phototransistors or photodiodes, can be used for detection. Sapphire, quartz, or glass can be a common substrate for Si-based VLSI electronic modules, optical modulators, and detectors because they are transparent to operating wavelengths and are fairly good heat dissipators.

Two demonstration hardware devices were built to show the advantages and potential of holographic optical interconnect techniques for use in a 3D optoelectronic computer architecture. The first device was aimed at high-speed multiple point-to-point optical interconnects for interboard and backplane data communication. Sixty channels, each with 500-MHz signals, were implemented to demonstrate simultaneous transmission in both configurations. The hardware consists of four electronic/optoelectronic board modules attached to an optical interconnect backplane, in a manner similar to conventional electronic backplane packaging.

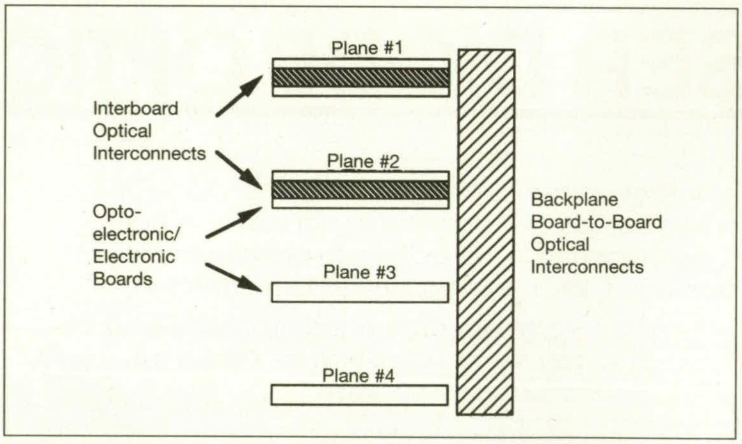


Figure 1. High-speed **Optical Interconnect** demonstration hardware architecture.

The second demonstration hardware device was configured as a 3D digital signal processor (DSP) architecture with optical interconnects realized between each pair of adjacent DSP boards. In total, twelve Texas Instruments C31 DSP chips, four per board, were used. Communications between the DSP chips on different boards were realized by a compact holographic interconnect technique. The hardware was interfaced with a PC as a host computer and an automated target recognition applications program was successfully run on the optically interconnected system.

The high-speed optical interconnect demonstration is shown schematically in Figure 1. Four optoelectronic/electronic planes, each consisting of one or two optoelectronic/electronic boards, are plugged into a backplane board-to-board passive optical interconnect structure, in a manner similar to conventional electronic boards and backplanes. Each board consists of several laser diode transmitters, photodetector receivers,

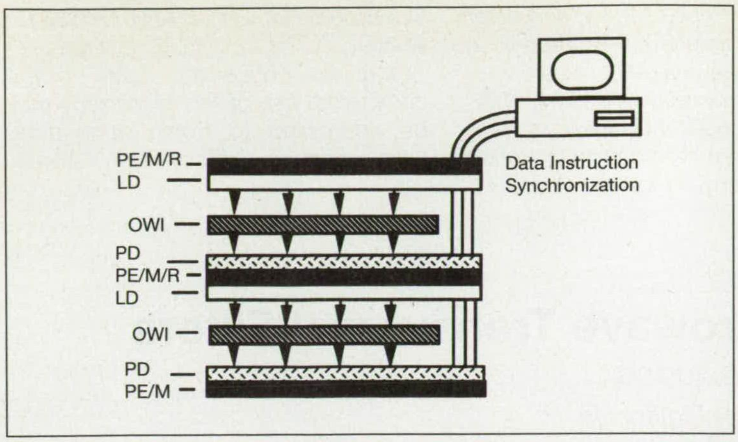


Figure 2. Parallel **3D Optoelectronic Computer** architecture. PE = processing element; M = memory; R = router; LD = laser diode; PD = photodetector; OWI = optical waveguide interconnect.

and interface I/O circuits that enable the input of external signals or the output of detected signals to be examined (e.g., with an oscilloscope). Signal can also be provided by an internal 500/550-MHz oscillator. The four planes are configured to communicate via the holographic waveguide backplane interconnect structure. Two of the four planes (nos. 1 and 2) are also configured to perform intraplane optical interconnections. In each of these two arranged optoelectronic/electronic planes, a holographic optical waveguide interconnect plane is sandwiched between two optoelectronic/electronic boards. The holographic plane provides interboard communication paths between the two boards. The data bandwidth of this demonstration is set to 500/550 MHz to show the high-speed performance of optical interconnect operations. The entire volume of the demonstration package is 10 X 5 X 5 inches^3.

The parallel 3D optoelectronic computer demonstration system was designed and constructed to demonstrate multiprocessor-based computing using optical interconnects. The architecture for this hardware is shown schematically in Figure 2. The hardware consists of three layers, each having direct communication paths with a host computer (HC), in this case a PC. It is used to provide data, instructions, and synchronization to the various processor nodes. Each layer (or board) contains four processor nodes, each with its own electronic signal processor, and an optical interconnect circuit. The connections between processors within a single layer are electrical, whereas the connection between layers is optical.

There are four unidirectional optical waveguide interconnects between adjacent boards, the means of interconnecting the nodes on different layers. Since the data flow scheme is based on a single-instruction multiple-data parallel pipeline, the nodes in the first layer only contain laser diodes and driver circuits, and nodes in the third layer only photodetector receiver circuits. Nodes in the second layer have both. The communications scheme between boards can be summarized as follows: board 1 can only transmit data to board 2 through optical channels; board 2 can only receive data from board 1 and can only transmit data to board 3 through optical channels; and board 3 can only receive data from board 2.

Each optical transmitter converts 32-bit parallel data to serial format, adds start and stop bits for a total of 36 bits, and transmits data serially. There is no interrupt on "transmit shift register empty" but only a status bit. Each optical receiver converts 36-bit serial data to a 32-bit parallel word (the starts and stops are thrown away) and generates an interrupt whenever a complete word is received. There is no error detection and correction. The maximum serial data transfer rate is 40 Mb/sec.

Similarly, communication between nodes within a single board can be summarized as follows: there are four independent 32-bit bidirectional latches, one per pair of adjacent nodes. The transfer is one word at a time. Data written to the latch automatically generates an interrupt to the destination node. Data read from the latch automatically generates an acknowledge to the source node. There is a common system clock for all three boards, and the clock signal is distributed electrically (there is no clock signal encoded in the data during optical transmission).

The technology developed provides a host of novel device and system concepts that can make major breakthroughs in the areas of supercomputing, parallel computing and signal processing. The benefits of optical interconnects, such as high channel density, high data bandwidth, no cross-coupling, global out-of-plane/in-plane connections, and no electromagnetic interference, can be fully utilized at the level of computer integration. The demonstrated 3-D optoelectronic computer, based on holoplanar interconnect technology, represents the first effort of its kind in devel-

oping small-size signal processing and supercomputing packaging technology through state-of-the-art microelectronics, optoelectronics, and optics.

This work was performed under **Rome Laboratory** *contract no. F30602-91-C-0611 by Freddie Lin, Cong Nuygen, Robert Minow, and Peter Bumacod of Physical Optics Corporation Research and Development Department, 20600 Gramercy Place, Building 100, Torrance, CA 90501. For further information contact the research team or Robert Kaminski, Rome Laboratory, RL/C3BC, 525 Brooks Rd., Griffiss AFB, NY 13441-4505.*

Inquiries concerning rights to the commercial use of this technology may be addressed to Rome Laboratory, Office of the JA, Griffiss AFB, NY 13441.

Adjustable Fiber Optic Microwave Transversal Filters

Weights of taps in fiber optic delay lines are adjusted.

NASA's Jet Propulsion Laboratory, Pasadena, California

Microwave transversal filters implemented as adjustable tapped fiber optic delay lines are being developed. The main advantages of these filters (in comparison with conventional microwave transversal filters) are small size, light weight, no need for matching of radio-frequency impedances, no need for shielding against electromagnetic radiation at sub-optical frequencies, no need for mechanical tuning, high stability of amplitude and phase, and active control of transfer functions.

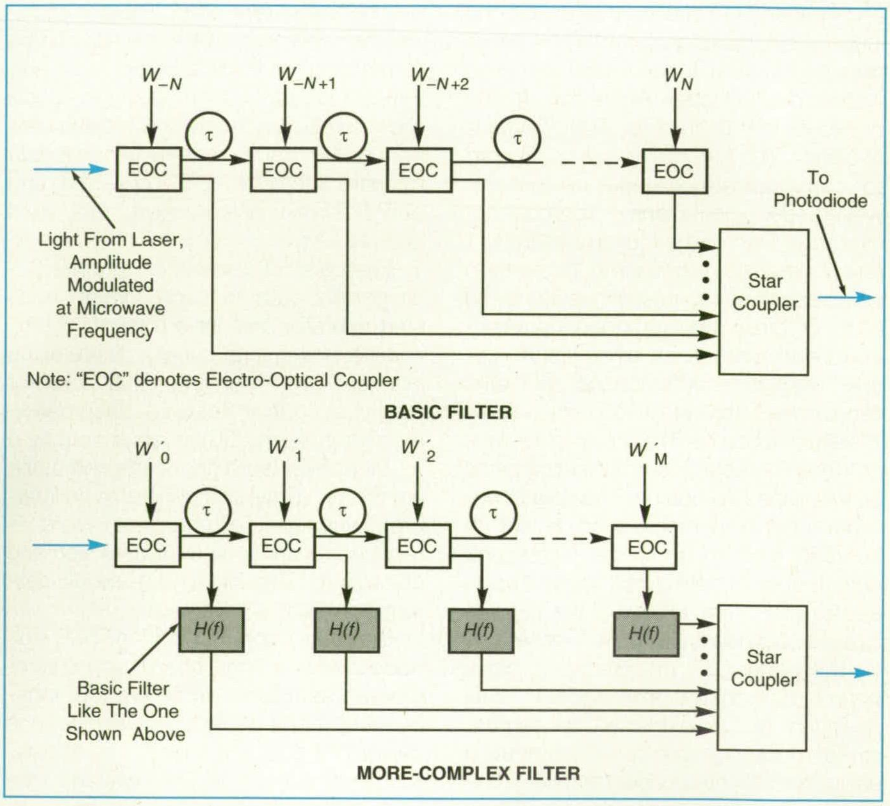
The top part of the figure illustrates a typical filter of this type. The segments of the delay line are single-mode optical fibers that are made in equal lengths to provide equal, fixed incremental delays, τ, between the taps. The tap weights (the relative strengths of signals taken out through the taps) are adjusted by varying the bias voltages applied to electro-optical couplers that are integrated with the single-mode optical fibers.

Light from a laser is intensity-modulated at the microwave frequency of interest and transmitted to the first electro-optical coupler along the delay line. The optical signals tapped at the various couplers along the delay line are summed in a star coupler, the output of which is sent to a photodiode for conversion into the filtered microwave signal. By adjustment of the tap weights, the filters can be reconfigured easily to perform various functions; for example, low pass, high pass, or band pass. These adjustments and reconfigurations can be performed very quickly — at gigahertz rates.

The transfer function, $H(f)$, has the following periodic form:

$$H(f) = \left(\sum_{n=-N}^{N} W_n e^{-j2\pi nf\tau} \right) e^{-j2\pi Nf\tau}$$

where W_n is the nth tap weight, f is the microwave frequency, and the total number of taps is $2N+1$. The tap weights needed to obtain a given filter function can be chosen by taking the first $2N+1$ terms of a Fourier-series expansion of the desired frequency and phase response.



Microwave Transversal Filters implemented as adjustable tapped fiber optic delay lines offer advantages over conventional microwave transversal filters.

To obtain additional flexibility for optimization of the filter function, one could synthesize a more complex design. For example, a $2N+1$-tap fiber-optic transversal filter with transfer function $H(f)$ could be incorporated into each tap of an M-tap fiber-optic transversal filter of transfer function

$$H'(f) = \sum_{m=0}^{M} W'_m e^{-j2\pi mf\tau}$$

as shown in the lower part of the figure. In this case, the overall transfer function would be given by $H_t(f) = H(f)H'(f)$, and two sets of tap weights (W_n and W'_m) would be available for adjustment to optimize the filter function.

Of course, uncontrolled variations in the lengths of the fibers and in the tap weights can be expected to alter the performance of a filter. A computer program has been used to analyze the effects of random variations of the tap weights (as much as 4 percent) and of the lengths of the fibers (as much as 5 percent). This analysis showed that when the tap weights and lengths of fibers deviate from their design values, degradation in the performance of the filter will be evident.

This work was done by Mehdi Shadaram, George F. Lutes, Ronald T. Logan, and Lutfollah Maleki of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 93*** *on the TSP Request Card.*
NPO-18711

Generating Submillimeter-Wave Frequencies From Laser Pulses

Phase delays between optically activated semiconductor switches would determine output carrier frequencies.

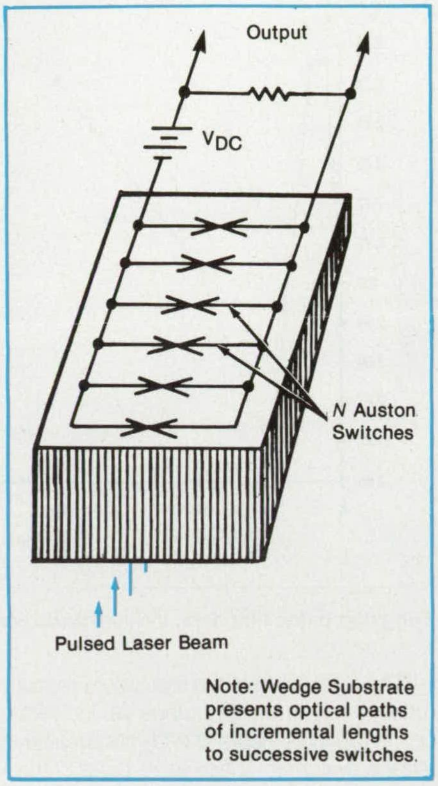
NASA's Jet Propulsion Laboratory, Pasadena, California

Semiconductor photoconductive switches would generate electrical pulses containing submillimeter-wavelength carrier signals (frequency between 300 and 3,000 GHz) and harmonics thereof when illuminated with short-rise-time ($\leq$1-psec) pulses from lasers. A device of this type could be used as a local oscillator in a heterodyne submillimeter-wave receiver. The electrical output of the device would be coupled via a transmission line, waveguide, or antenna to the mixer circuitry of the receiver.

The simplest device of this type would include N semiconductor photoconductive switches connected electrically in parallel by two geometrically parallel conductors and placed at equal intervals along the conductors (see figure). The photoconductive switches could be Auston-type switches, which consist of gaps between metal contacts deposited on a highly resistive, photoconductive material like semi-insulating GaAs or InP. When a gap in an Auston switch is illuminated, electron-hole pairs are created, and the path through the semiconductor between the contacts becomes highly conductive (the switch closes).

The switches in the device would be biased with a voltage, V_{dc}, from a common source. When a pulse of light arrives perpendicularly to the plane of the device or along any other suitable direction, the switches would close sequentially at intervals equal to the difference between the times of arrival of the pulse at each switch. The closure of each switch would give rise to a pulse of current, which would propagate along the parallel conductors to an output terminal. Each pulse of light would give rise to N electrical pulses, each delayed with respect to the next or previous pulse by an interval that would depend on the delay in propagation along the parallel conductors and the difference between the times of arrival of the optical pulse at successive switches. Since N pulses are generated between laser pulses, the effective pulse-repetition rate is increased by N over that of the laser. The amplitude of the pulse harmonic at this pulse-repetition frequency will likewise be increased by N.

The device could be illuminated perpendicularly from the back, as shown in the figure, and the substrate could be made as a wedge so that the delay between arrival of successive optical pulses could be made a function of the index of refraction of the substrate and the thickness of the substrate at the location of each switch. Alternatively, or in addition, the fundamental pulse-repetition frequency (which is the rate of arrival of switch-closing pulses at the output terminal) could be adjusted by adjusting the angle of illumination to obtain the desired interval between arrival of laser pulses at successive switches.



N **Electrical Pulses** would be generated by each laser pulse. Thus, the fundamental output frequency would be N times the laser-pulse-repetition rate.

This work was done by Michael G. Spencer and Joseph Maserjian of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 194*** *on the Reader Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office — JPL; (818) 354-5179. Refer to NPO-18547.

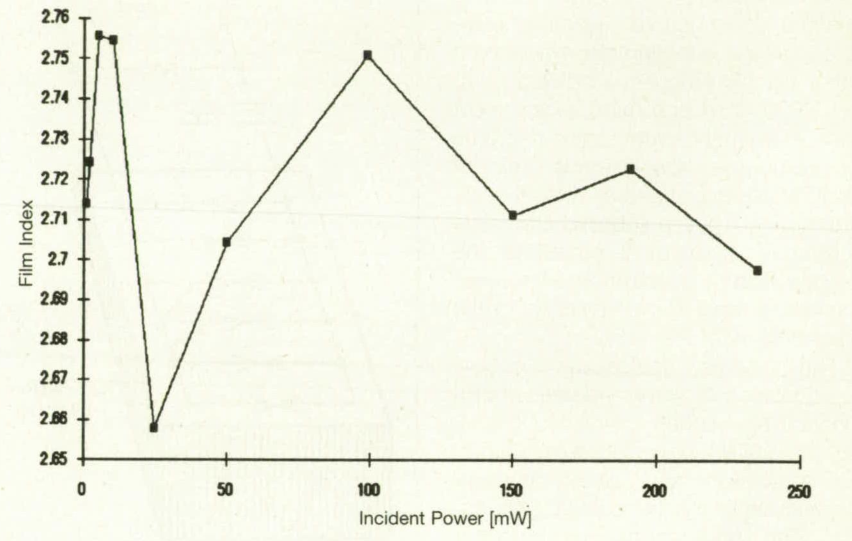
Nonlinear Interface Optical Switches Handle Broadband Signals

Cluster semiconductor interface switches show promise for all-optical switching.

Rome Laboratory, Photonics Center, Griffiss Air Force Base, New York

The nonlinear interface optical switch (NIOS) consists of two layers: a substrate of an ordinary linear dielectric and a second thin layer consisting of a dielectric with an intensity-dependent index of refraction, *i.e.*, an optical Kerr-effect medium. This nonlinear layer has an index of refraction at weak input intensities that is slightly lower than the linear medium's. When used for optical computer switching, all input beams are at or near the critical angle for total internal reflection (TIR). The beams are adjusted so that with no control beam or pulse, the data beam will undergo TIR, but when a control beam is present, the change in the nonlinear medium's index of refraction will lead to a transmission of the data beam through the interface.

In general, the major advantages of this type of switch are that, because it does not use a resonator, it is capable of extremely fast response times, and if the nonlinearity itself is nonresonant, it can switch data signals of broad spectral bandwidth.



Tungsten oxide film data: incident power vs. film index at 30° angle.

The switches are made of nonstoichiometric tungsten trioxide cluster material. Tungsten oxides are tough refractory materials able to withstand high temperatures, and are familiar as the most common material used to make magnetron anodes. Bulk tungsten trioxide (WO_3) is a photorefractive material. It is also photochromic and electrochromic.

The material is produced by laser chemistry of organometallics in Prof. Joseph Chaiken's laboratory at Syracuse University. Other candidate materials, produced by various methods, are also under investigation. The 10-100-angstrom size range of the clusters leads to a 10^6-10^8 increase of their optical nonlinearity as a result of electric field enhancement.

The figure shows the results of Fresnel model analysis of reflectance vs. incident power measurements of WO_3 nonlinear interface switches. These were done in the High-Speed Laser Facility of the Photonics Center. The change in film index due to a change in incident power from 1 to 2 mW is equivalent to a $\chi^{(3)}$ of 2.19×10^{-9} electrostatic units. This is comparable to results from organic polymer materials working in a narrow resonance wavelength. These same measurements showed that to properly match the film and substrate indices to achieve optical switching it will be necessary to use ZnSe as a substrate.

Optical switches based on nonlinear interfaces show considerable promise toward the goal of meeting the design criteria for switches for optical computing. Novel materials that can only be synthesized using laser chemistry of organometallics have a number of unique advantages for the design and fabrication of such switches.

This work was done by Joseph Osman of the Photonics Center, Surveillance and Photonics Directorate, **Rome Laboratory**, *and Prof. Joseph Chaiken, Department of Chemistry, Syracuse University. No further information is available. Inquiries concerning rights for the commercial use of this technology should be addressed to Rome Laboratory, Office of the JA, Griffiss Air Force Base, NY 13441.*

Adjustable Optical-Fiber Attenuator

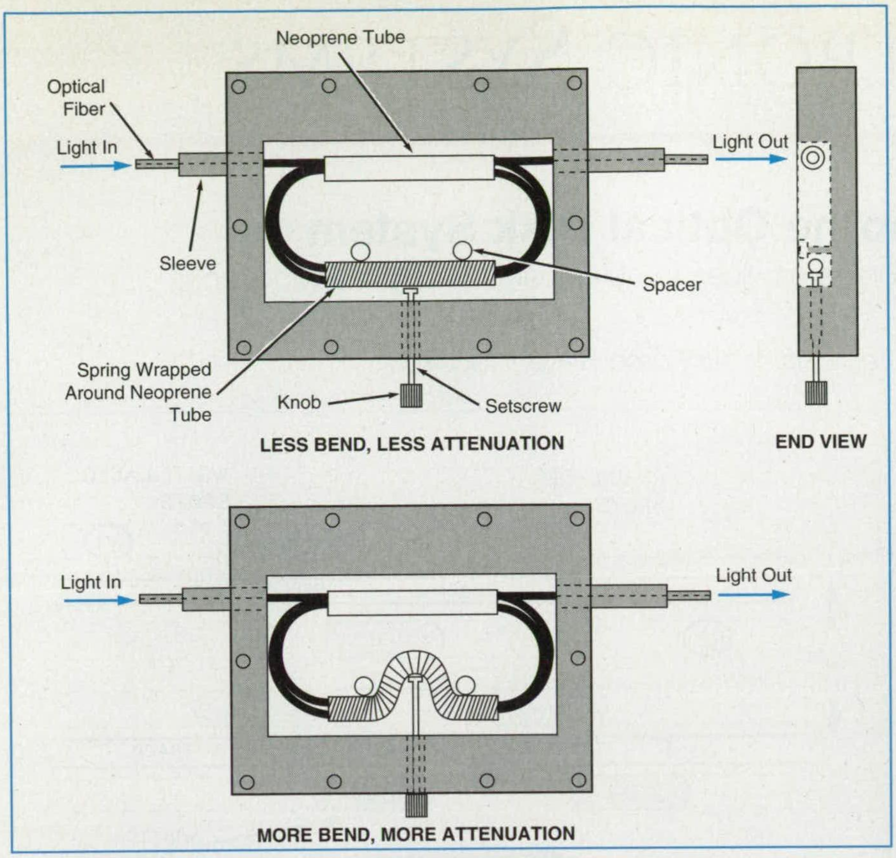
Attenuation is introduced without degradation of quality.

NASA's Jet Propulsion Laboratory, Pasadena, California

An adjustable fiber-optic attenuator utilizes bending loss to reduce the strength of the light transmitted along it. The attenuator functions without introducing measurable back-reflection or insertion loss. It is relatively insensitive to vibration and to changes in temperature. Its potential applications include cable television, telephone networks, other signal-distribution networks, and laboratory instrumentation.

The attenuator (see figure) includes a jacketless optical fiber looped 10 times through a pair of neoprene tubes, one of which is encased in a spring. The bends cause light to leak out of the core of the fiber through the cladding, thereby attenuating the signal transmitted by the core. A setscrew with a knob presses against the side of the spring. Turning the setscrew so that it projects farther inward bends the spring and the fiber turns within it. Further turning decreases the local bending radius, thereby increasing the attenuation.

This work was done by Mike F. Buzzetti of Caltech for **NASA's Jet Pro-**



The **Bending Radius of the Looped Fiber** and the amount of attenuation (which increases with decreasing radius) is changed by turning the setscrew. The farther the setscrew is extended into the housing, the greater the attenuation.

pulsion Laboratory. *For further information,* ***write in 180*** *on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

William T. Callaghan, Manager
Technology Commercialization
(M/S 79-23)
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Refer to NPO-18901 volume and number of this Laser Tech Briefs issue, and the page number.

ELECTRONIC SYSTEMS

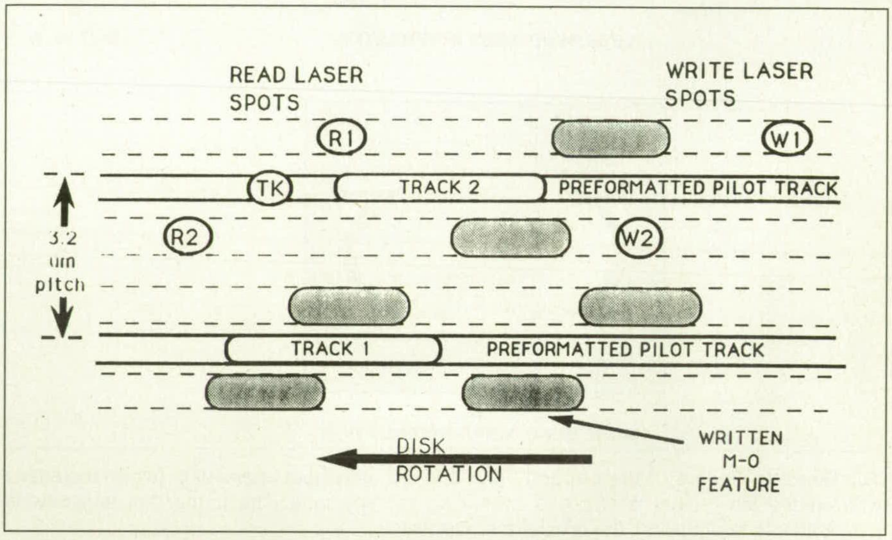
A Flight-Tested Airborne Optical Disk System

High-performance optical disk storage provides reliable operation under a wide range of deployment conditions.

Rome Laboratory, Photonics Center, Griffiss Air Force Base, New York

The strategic/tactical optical disk system (S/TODS), a high-performance rewritable data storage and retrieval system, demonstrated flight readiness by operating successfully during flight tests under a wide range of operational conditions. S/TODS, a rugged optical disk system designed for sustained reliable operation under severe military conditions, stores 12 gigabytes of data on a single 14-inch-diameter removable and erasable optical disk. A multiple-laser-beam recording technique provides a data throughput rate of more than 3 megabytes per second sustained and 7 megabytes per second burst. A powerful error detection and correction algorithm and direct read-after-write provides a bit error rate of less than 10^{-12}.

In traditional optical disk storage systems, a single laser beam records, reconstructs, and erases digital data. Successful operation requires that the position of the final objective lens be adjusted in real time to maintain focus and tracking while the disk is spinning. The S/TODS approach is to use multiple laser beams for dual-track recording and immediate read-after-write verification. This is accomplished through an improved focus/track actuator mechanism and an advanced servo-electronics design. Dual-track recording and erasure is achieved with a commercial dual-channel laser diode array. The remaining three laser beams accomplish disk tracking and immediate-read verification. All five beams pass through a common set of optical components and are simultaneously focused on the spinning disk surface.



Track format for the **S/TODS data storage and retrieval system**.

The flight tests were performed on RC-135 aircraft over a three-day period. The testing included midair refueling, tactical descents, 60° banks, touch-and-gos, turns up to 2 g in force, and heavy vibration. No data was corrupted or lost throughout the testing, and there were no excessive BERs or hardware failures.

Commercial applications of this disk system might be airborne data collection and environmental sensing, aerial mapping and surveying, airline entertainment systems such as CD-quality music and interactive games, and database storage.

This work was done under the supervision of Fred Haritatos and Capt. Brady Canfield with development sponsorship by **Rome Laboratory**. *Inquiries concerning rights for commercial use of this technology should be addressed to Rome Laboratory, Office of the JA, Griffiss Air Force Base, New York 13441.*

High-Resolution Optoelectronic Shaft-Angle Encoder

The absolute angle (as well as increments of angle) can be measured to high resolution.

Goddard Space Flight Center, Greenbelt, Maryland

An improved optoelectronic encoder measures the absolute angle to which a shaft has been rotated. Some older, moderately priced shaft-angle encoders offer high resolution in the sense that they measure small increments of angle precisely, and they can keep track of accumulated increments to yield absolute angles, but they can lose the absolute-angle data in the event of electromagnetic interference or loss of power. Other older, moderately priced encoders offer absolute angular measurements at low to moderate resolution, while the older encoders that offer the highest angular sensitivity and resolution can cost as much as $100,000 (at 1994 prices). The improved encoder costs little more than older, less capable encoders do, yet it measures absolute angles at high resolution and does not lose absolute-angle data because it generates those data anew with each reading at up to 1,000 times per second. Furthermore, it can accumulate increments to measure the total angular interval through which a shaft has been turned (including an unlimited number of complete turns), as long as power remains on.

The improved optoelectronic encoder (see figure) includes a polygonal mirror wheel affixed to the shaft. A binary or gray-code pattern on the wheel is read by a stationary binary or gray-code reader, which puts out a coarse-resolution signal that indicates the shaft angle to within

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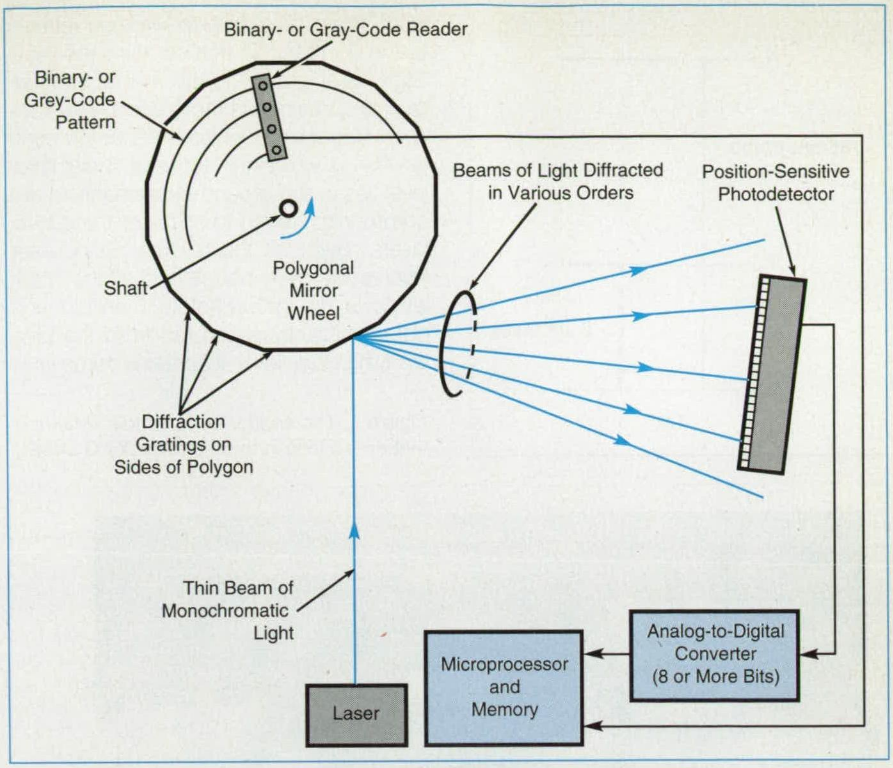
the angle subtended by one side of the polygon. In other words, the gray code identifies which side of the polygon is being studied. The output of the gray-code reader can also be used for tachometry.

A flat, low-line-density diffraction grating with the lines parallel to the axis of the shaft is patterned on each side of the polygon. A thin beam of monochromatic light from a laser strikes one of the gratings (which one depends on the shaft angle), giving rise to multiple beams diffracted in various orders. These beams strike a charge-coupled device or other position-sensitive photodetector. The output of the photodetector is digitized and fed to a microprocessor.

The positions of, and distances between, the diffracted light spots on the photodetector are related in known ways to the (1) relative positions of the laser, shaft, and photodetector, (2) the orientations of the laser and photodetector, (3) the number of facets and size of the polygon, (4) the density of lines on the diffraction gratings, (5) the wavelength of the laser beam, and (6) the angle of whichever side of the polygon intercepts the beam. By use of algorithms and calibration data that implement these relationships, the microprocessor computes the angle of the intercepting side to fine resolution from the locations of the light spots on the photodetector. The microprocessor also obtains the identity of the intercepting side from the output of the binary- or gray-code reader. Of course, once the identity and angle of this side are known, the absolute shaft angle is known. Occasionally, the beam intercepts a corner of the polygon, so that diffracted light spots emanating from two adjacent sides can appear on the photodetector.



The **Diffraction Pattern on the Photodetector** depends on the angle of the side of the polygon that intercepts the laser beam and thus yields fine-resolution data on the shaft angle within an angular interval subtended by one side of the polygon. The identity of the intercepting side (coarse-resolution angle information) is determined from the output of the binary- or gray-code reader. From these two sets of data, the absolute shaft angle can be determined.

The microprocessor can be programmed to function in this situation and even to take advantage of the continuity of angular information afforded by the simultaneous data from two sets of diffraction spots.

This work was done by Douglas B. Leviton of **Goddard Space Flight Center**. *For further information,* ***write in 136*** *on the Reader Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center, Mail Code 204, Greenbelt, MD 20771; (301) 286-7351. Refer to GSC-13543.

Diode End-Pumped 2-Micrometer Tm:YAG Laser

Using a scalable diode end-pumping technology, a 2-micrometer thulium:YAG laser is being developed for medical researchers.

Lawrence Livermore National Laboratory, Livermore, California

Chief among the many advantages of using semiconductor diode laser arrays as replacements for flashlamps in the excitation of solid-state lasers is the ability to focus the outputs from such arrays to small spot sizes and high intensities. The ability to generate high pump intensities has significantly expanded the number of ions and transitions that can be exploited for use in practical laser systems. Along with this increase has come an increase in the number of wavelengths that can be generated by diode-pumped solid-state (DPSS) lasers and so an increase in the number of applications that can look toward DPSS lasers for a solution to their specific problems.

Researchers currently are using a scalable diode end-pumping technology previously developed (see *Laser Tech Briefs*, Winter 1994, Vol. 2, No. 1, p. 32) to demonstrate a Tm:YAG laser capable of generating 20 W of continuous 2-micrometer laser radiation. This laser is to be delivered to medical researchers at the Wellman Laboratories of Photomedicine in Boston, Massachusetts, later this year for use in laser-assisted surgical procedures. Because such radiation is strongly absorbed by water, it has many useful medical applications such as cutting and welding. Additionally, because 2-micrometer radiation can be conveniently delivered through optical fibers, fiber-coupled laser systems such as the one being developed are being investigated for minimally-invasive surgical procedures such as laparoscopy.

Figure 1 depicts the energy levels of the Tm^{3+} ion that are utilized in this laser. Population is promoted from the ground $^3H_6$ manifold to the $^3H_4$ manifold by pumping at 785 nm with AlGaAs diode

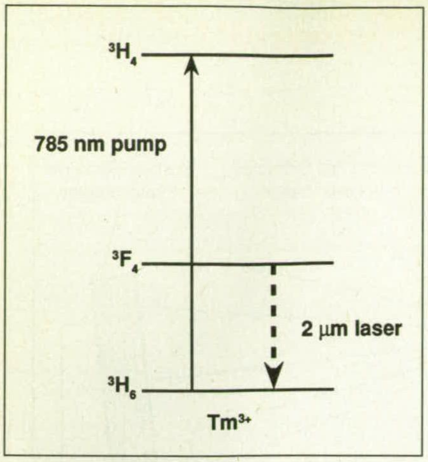


Figure 1. The energy levels of the TM3+ ion that are utilized in the 2-μm **Tm:YAG Laser**.

laser arrays. This population then relaxes to the $^3F_4$ manifold that contains the initial Stark laser level. The terminal Stark laser level is contained in the ground $^3H_6$ manifold. Spectroscopic laser schemes such as this in which the terminal Stark laser level lies in the ground-state manifold are commonly referred to as quasi-three-level lasers. Because the terminal Stark laser level is thermally coupled to all the Stark levels in the ground-state manifold and not significantly separated from the lowest-lying Stark level, it contains some fraction of the ground-state manifold's population as determined by the Boltzmann distribution. This results in an absorption by the sample at the laser's emission wavelength that must be overcome by pumping.

Traditionally, the presence of such absorption losses in a laser has meant that the laser had to be operated at cryogenic temperatures such that the population present in the terminal Stark laser level at room temperature becomes frozen out. Such cryogenic operation was the only practical way to lower the threshold of such systems enough to overcome the deleterious effects of ground-state absorption and enable lasing with conventional pump-excitation sources such as flashlamps. With the advent of semiconductor laser diode arrays and their ability to generate very high pump intensities, many of the systems that were only possible at cryogenic temperatures previously are now not only possible but practical at room temperature. This room-temperature operation results from the ability of such arrays to pump laser samples to much higher excited-state fractions than was previously possible, thus overcoming ground-state absorption losses by brute force.

Figure 2 is a schematic of the laser. In the photograph, the microchannel-cooled microlens-conditioned stack of laser diode bars and the lensing duct that define the scalable diode end-pumping technology are visible. The stack of arrays consists of 25 packages, each containing one linear centimeter of diode bar material. Micro-cylinder lenses collect and collimate the output of each of these laser bars, allowing it to be efficiently delivered to the end of the lightly doped Tm:YAG rod, 5 cm long by 3.2 mm in diameter. The lensing duct serves to channel the radiation from the diode arrays to the rod, using a combination of lensing at its curved input face and total internal reflection (TIR) on its canted planar sides. The barrel of the YAG rod is polished so that the delivered pump light is confined within the rod by TIR and can be channeled down the rod as it is absorbed by the Tm.

In order to assess thermal management issues in the Tm:YAG rod, particularly at its pump input end, a breadboard has been constructed and operated using an 808-nm pumped Nd:YAG rod that lased at 1.06 μm. This breadboard was operated reliably at 25 W of continuous output power using a Nd:YAG rod 2 cm long by 3.2 mm in diameter. Of particular importance to the reliable operation of lasers using this end-pumping architecture is to avoid frustrating the TIR of the pump light within the laser rod. This requires careful attention to the O-rings used to seal the rod in its water-cooling jacket. Conventional black O-rings

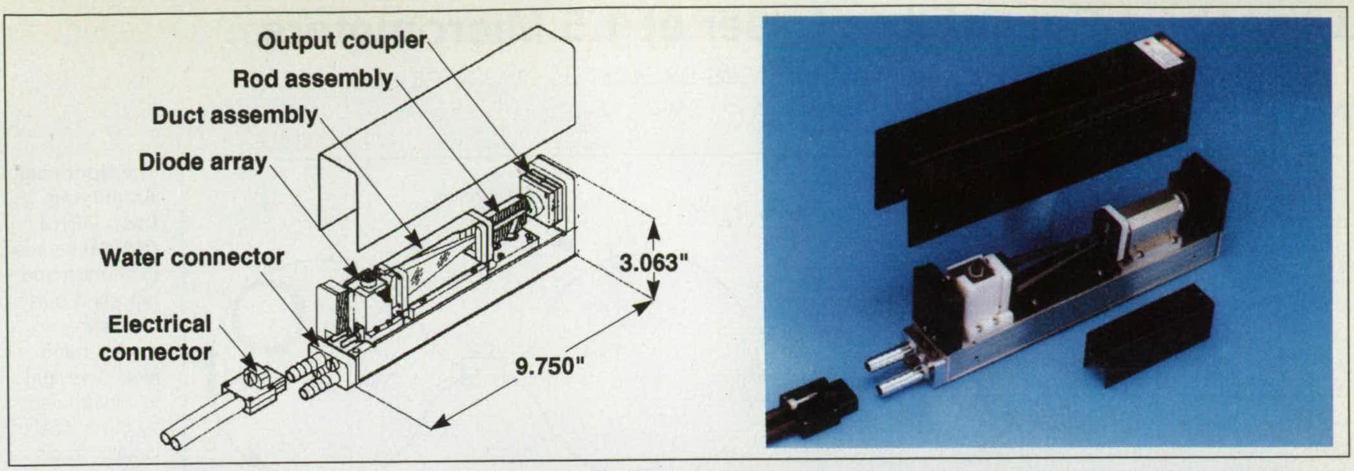


Figure 2. Exploded diagram of the laser showing the **Diode Array and the Lensing Duct Assembly** in its structure.

against the polished barrel of the YAG can effectively frustrate the TIR of the pump light, leading to local heating of the rod, and so must be avoided.

In addition to the CW laser shown in Figure 2, which is being developed for surgical purposes, a stretched cavity version of this laser is also under development. This variation is being constructed to allow the insertion of an acousto-optic Q-switch in the cavity. The Q-switched Tm:YAG laser is being delivered to medical researchers at the Beckman Laser Institute and Medical Clinic in Irvine, California, early next year for use in treating fertility problems in humans and livestock.

In summary, the scalable diode end-pumping technology is being exploited in two versions of the Tm:YAG laser. The technology was chosen for these lasers because of its ability to generate the required pump intensities and for its simplicity and commercial attractiveness.

This work was performed in the Advanced Applications Group of the Laser Program under the auspices of the U.S. Department of Energy by **Lawrence Livermore National Laboratory** *under contract W-7405-Eng-48. For further information contact Dr. Ray Beach, L-495, PO Box 808, Lawrence Livermore National Laboratory, Livermore, CA 94550.*

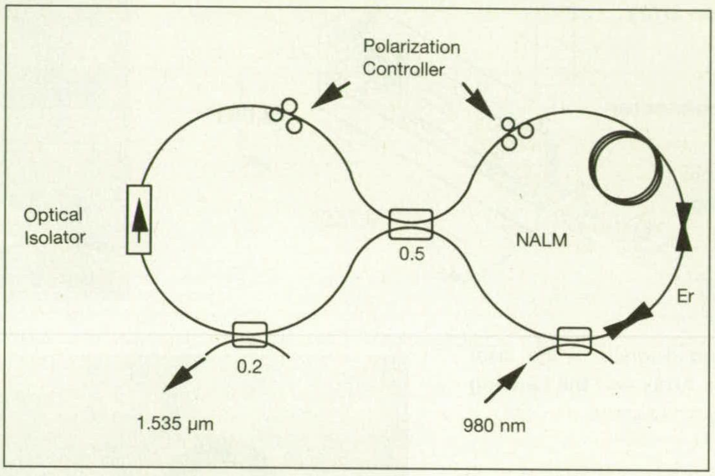
Inquiries concerning the rights for the commercial use of these inventions should be addressed to Norma Dunipace of the Technology Transfer Initiatives Program, L-795, PO Box 808, Lawrence Livermore National Laboratory, Livermore, CA 94550; (510) 422-5995.

Ultrashort-Pulse Fiber Laser at 1.5 Micrometers

A passively mode-locked laser produces pulses as short as 200 femtoseconds.

Naval Research Laboratory, Washington, D.C.

A fiber laser has been developed that can produce ultrashort pulses of light with no active drive mechanism. The principal applications for pulses of this kind are in high-speed soliton-based communications systems and as a scientific tool for optical probing of materials and circuits. In the past, pulses of durations less than 5 picoseconds could be generated only by cryogenically cooled color-center lasers requiring tens of kilowatts of electricity, the equivalent in water-cooling capacity, and at a cost close to $100,000. With the new technology, equivalent pulses can be produced using air cooling and a standard wall plug for closer to $30,000.



The **Nonlinear Amplifying Loop Mirror (NALM)** serves to shorten and amplify a pulse circulating in the left-hand loop. The light is constrained by the optical isolator to circulate in a clockwise fashion in the left-hand loop.

High-speed optical communications, optical probing of electrical circuits and semiconductor materials, and short-pulse fiber sensors all require a compact source of short optical pulses compatible with fiber transmission. Utilizing recent advances in erbium-doped fibers and nonlinear switching, a fiber laser has been created that has all fiber-compatible components and requires no electrical microwave drive to mode-lock the laser.

The figure eight Laser (F8L) is a ring fiber laser with an intensity-dependent optical element included in the cavity to cause the laser to produce ultrashort pulses. The gain for the laser is provided by the same erbium-doped fiber amplifier that is in use throughout the communications community. This makes the source immediately compatible with high-speed soliton communications systems and research. The erbium amplifier is included in what is called a nonlinear amplifying loop mirror (NALM). This element provides pulse shortening and amplification for the pulse circulating in the cavity. It is the addition of this element that gives the laser its distinctive shape and thus its name. The NALM also is responsible for the production of pulses within the laser.

The operating characteristics of the F8L are determined by the dispersion properties of the fiber and the switching characteristics of the NALM. The fibers are chosen such that they can support propagation of soliton pulses. The resulting pulses are cleaner, more stable, and significantly shorter than those obtained with other all-fiber lasers. The shortest pulses produced in the laboratory from a laser of this kind are 90 femtoseconds, with pulses as short as 200 fs being typical.

The laser can produce tens of milliwatts with repetition rates into the gigahertz regime (depending on the amplifier's saturation power). The laser, apart from the pump laser diode and its current source, could easily fit in a CD case, making it suitable for inclusion as a source in test equipment.

The laser has also been fabricated using other rare-earth-doped fibers. Most notably, a praseodymium-doped fluoride fiber was included to make a F8L operating at 1.3 micrometers. Rare-earth-doped fiber lasers have been demonstrated in discrete bands across the 1-to-2-micrometer wavelength range, and any of these wavelengths should be accessible to the technique. Subsequent investigation has revealed operational dependencies such that the laser can now be engineered to produce the desired pulsewidth for a particular application.

This work was done by Irl N. Duling III for the **Naval Research Laboratory**. *For further information,* ***write in 132*** *on the Reader Information Request card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to Dr. Richard H. Rein, Technology Transfer Office, Code 1004, Naval Research Laboratory, Washington, D.C. 20375-5320; (202) 767-3744.

Compact and Rugged Optical Systems for RF Spectrum Analysis

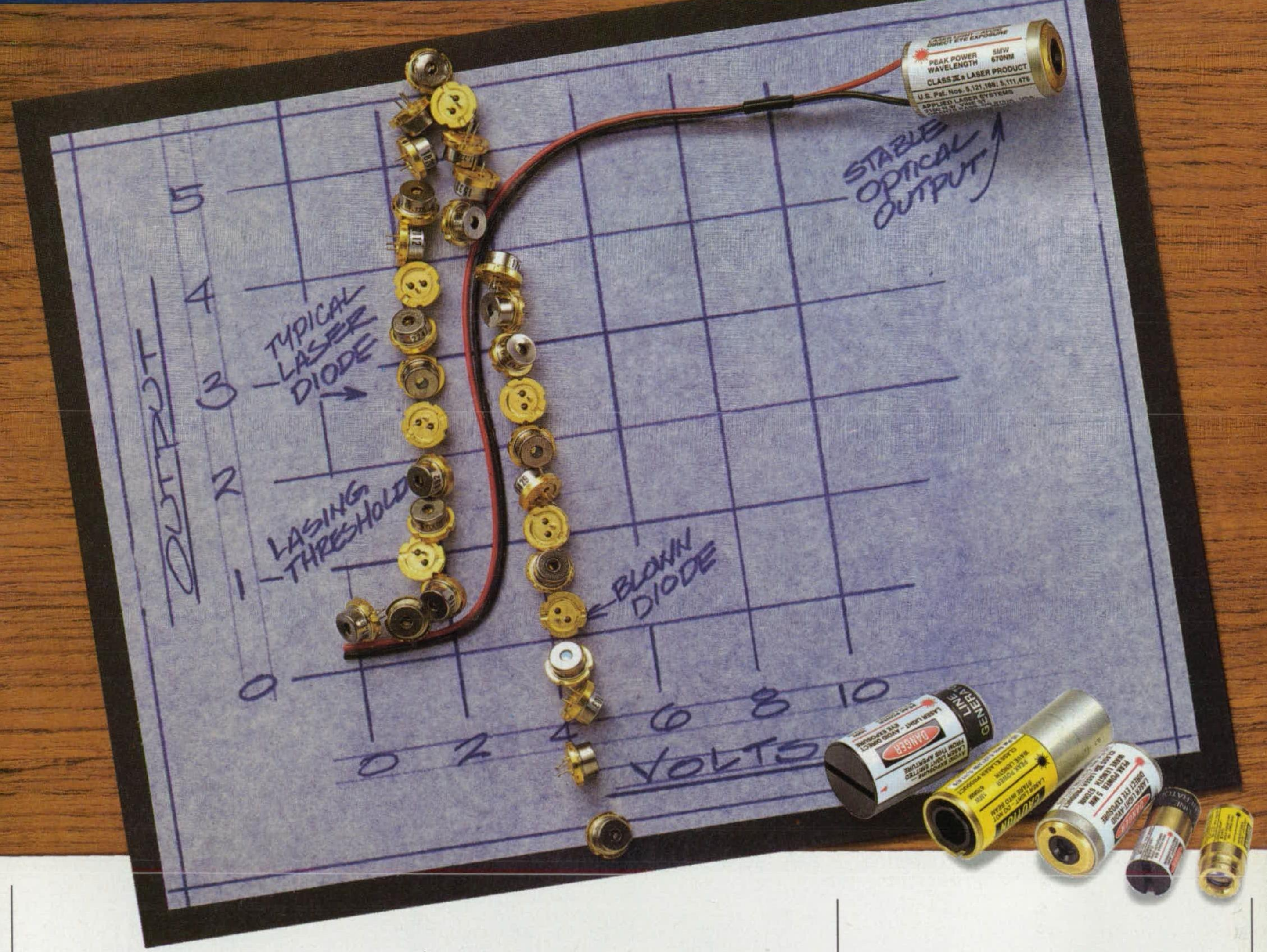
Optical means are being employed for parallel processing of communication- and radar-band signals.

Naval Research Laboratory, Washington, D.C.

Optical systems are being developed for analyzing communication and radar signals because of their small volume and low power consumption. For example, an RF spectrum analyzer has been constructed that occupies 6 cubic inches, consumes about 10 W of power, and is capable of handling 1 GHz of bandwidth. This is orders of magnitude better than competing technology. The photograph shows the spectrum analyzer with the cover removed (top) and optical components separated (below). Other optical spectrum analyzers can handle communications bandwidths (~25-50 MHz) with high resolution (25-50 kHz). Performance of the optics has been demonstrated in shock and vibration environments and over military temperature ranges. The output of such spectrum analyzers can be either the amplitude of the spectral components only, or both the amplitude and the phase, usually on an IF carrier.

The key to the spectrum analyzer's performance is the optical modulator technology: acousto-optics (AO). The AO (or Bragg) cell, a small crystal at the mid-

What Goes Up, Usually Comes Down...



Unless

...the laser diode destined for your product application is completely protected against the forces of electro-static discharge, temperature and handling abuse. That's because a raw laser diode is a fragile and highly volatile device with extreme threshold behavior that will quickly "blow up" under unstable environmental conditions. The typical laser diode is capable of turning on in "one millionth" of a second...and one very short "mistake" usually results in total destruction, rendering the laser diode useless. Applied Laser Systems (ALS) has solved this problem and makes the laser diode usable in the real world.

So, while it may seem practical to engineer your laser product "from the ground up," it makes far more sense to bypass the frustrating process of trying to stabilize the laser diode by simply "plugging in" our patented VLM™ product directly into your application. Our modular system is so user friendly, all you have to do is add a power supply.

Simply put, the ALS Visible Laser Module, or VLM™ product is the most advanced laser module system on the market today. Our miniature design incorporates the laser diode, drive circuits, and sophisticated optics into one tiny, self-contained, shock resistant package, allowing us to maximize power efficiency while protecting the internal circuitry from electro-static discharge, spiking overload and reverse polarity. In short, the VLM™ product makes the fragile laser diode virtually indestructible.

And with a field failure rate of less than 1 percent, Applied Laser Systems supports its products with a full **two year warranty,** setting the industry standard. In addition, a small green LED indicator is mounted on the rear of each module to indicate when the laser is operating...a safety factor that ALS alone provides.

The versatile VLM™ product comes ready-to-use in a variety of beam configurations and wavelengths, in both the visible and infrared bands. Modules can easily be integrated into a wide variety of applications that require precision and accuracy, such as alignment and positioning, counting and timing, signal transmission, testing and measurement, and illumination... right out of the box.

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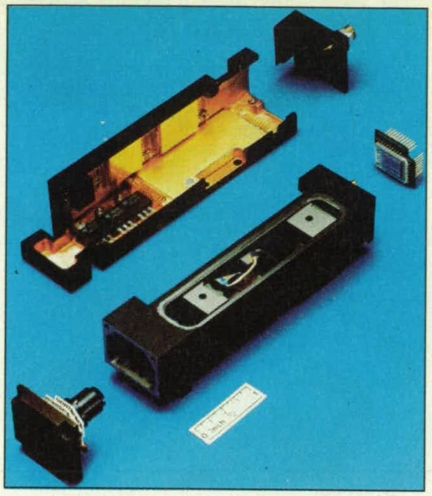
For More Information Write In No. 511

dle of the bench in the photograph, is a converter from the electrical/RF domain into the optical domain. High-efficiency high-bandwidth Bragg cells have been developed that require less than 1 W of wall-plug power. The Bragg cell decomposes the laser beam into as many components as exist in the RF drive signal. Hence, a two-tone signal produces two output light beams separated in angle. The output beams are detected with a photodetector and postprocessed. The number of spectral channels typically ranges from 25 to 1000, depending on processor design.

Other keys to the compactness of the spectrum analyzer are the laser diode and laser optics technology (similar to those in CD players), shown on the left side of the photo, and the VLSI circuit technology for photodetectors and postprocessing, shown on the right side. The required laser diodes had to be high-power (100 mW), with excellent temporal- and spatial-mode stability, and able to survive in all environments. The photodetectors were developed for high speed and high dynamic range, the postprocessing circuits for processing of many channels in parallel.

Essential to achieving high dynamic-range performance in the optics is the use of computer-aided design (CAD) tools. These were used to generate an athermal design to keep the optics in perfect focus; *i.e.*, the optical focal lengths change with temperature-induced changes in the physical dimensions. These tools were also used to design mechanically and thermally robust structures, allowing identification of locations in the mechanical layout that would be particularly susceptible to shock, vibration, and temperature variations.



These spectrum analyzers have a variety of potential military and commercial applications. The analysis function allows radar warning to be performed wideband as a parallel process without danger of missing an emitter, such as can occur with scanning. This capability also can be applied directly to microwave spectroscopy applications: e.g., radio astronomy, where observation time is at a premium and the number of regions to be searched is large. Another area where the spectrum analysis function can be useful is in the demultiplexing of wideband communications. Up to 1000 channels can be spatially separated using processors like those described above without resorting to ultrahigh-speed time-division demultiplexing methods.

The Bragg-cell technology can also be used as a deflector and as wavelength-selective elements. Simultaneous deflection to many output ports can be advantageous in communications and computer networks with optical interconnection. Up to 1000 ports could be accessed with the optics discussed above.

The wavelength sensitivity of the acousto-optic interaction can be used to perform optical filtering. Optical filtering has many important uses. In particular, there has been great recent interest in using wavelength multiplexing for wideband optical communications. The above processors would now use known RF signals to separate out wavelengths or rapidly (less than 1 μs) select a waveband, instead of using a known wavelength to analyze the RF, as in the spectrum analyzer. The compact optics described above should be directly usable in these demultiplexing, interconnection, and optical filtering applications.

This work was done by Dr. John N. Lee of the Optical Sciences Division and Anthony Spezio of the Tactical Electronic Warfare Division of the **Naval Research Laboratory**. *Inquiries concerning rights for the commercial use of this invention should be addressed to Dr. Richard Rein, Technology Transfer Office, Code 1004, Naval Research Laboratory, Washington, D.C. 20375-5320; (202) 767-3744.*

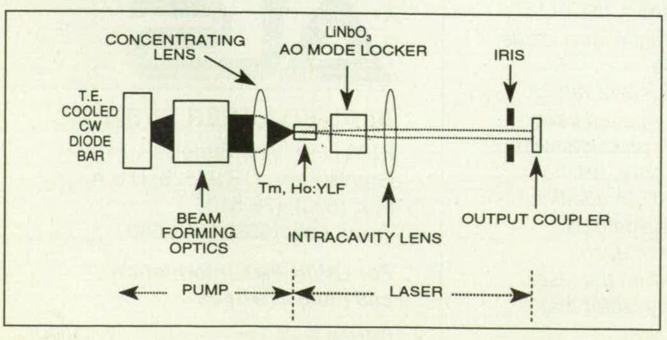
A Completely Solid-State Mode-locked 2-Micrometer Laser

Compact size and room-temperature operation make this laser a practical source of infrared subnanosecond pulses.

Wright Laboratory, Wright-Patterson Air Force Base, Ohio

Laser sources that can be tuned over much of the infrared region are of interest for a number of applications, such as remote sensing, chemical detection, and basic spectroscopy. But practical sources must be compact, efficient, and reliable. One possible solution is an optical parametric oscillator synchronously pumped by a mid-infrared mode-locked laser. An initial step in the development of such a device is the demonstration of mode-locked operation of a Tm,Ho:YLF laser at room temperature.

The figure illustrates the experimental laser setup schematically. A commercial GaAlAs diode laser tuned to operate nominally at 795 nm was used to pump a Tm,Ho:YLF crystal 5 mm long mounted on a water-cooled heatsink. The diode output was collected and collimated using a triplet-cylindrical lens combination, and then focused onto the Tm,Ho:YLF laser crystal using a lens with a 30-mm focal length. Up to 2.6 W of CW pump power was incident on the surface of the crystal, which was doped with 6% thulium and 0.5% holmium and absorbed two thirds of the incident power.



Schematic setup of the **Mode-locked Tm,Ho:YLF Laser.**

The Tm,Ho:YLF crystal surface facing the diode pump beam was antireflection (AR) coated at 795 nm and high-reflection (HR) coated at 2 micrometers to act as one end of the laser resonator. The other face was AR-coated at 2 micrometers. A lens with a 20-cm focal length, also AR-coated at 2 micrometers, was placed in

the 50-cm-long resonator to collimate the beam and compensate for the negative thermal lensing generated in the YLF crystal by the pumping. The output coupler was flat with 96% reflectivity.

The mode-locker consisted of a $LiNbO_3$ acousto-optic (AO) modulator crystal AR-coated at 2 micrometers and placed near the laser crystal. The computer-controlled frequency, adjusted to match the AO crystal, was approximately 150 MHz. At resonance, modulation power coupled into the $LiNbO_3$ crystal was 1 W.

Short-pulse detection was accomplished using a fast detector (800-picosecond response time) and an analog Tektronix oscilloscope with a 2-GHz bandwidth. True pulsewidth was measured using a scanning autocorrelator. Collinear second-harmonic generation in $LiIO_3$ was detected with a cooled S1 photomultiplier.

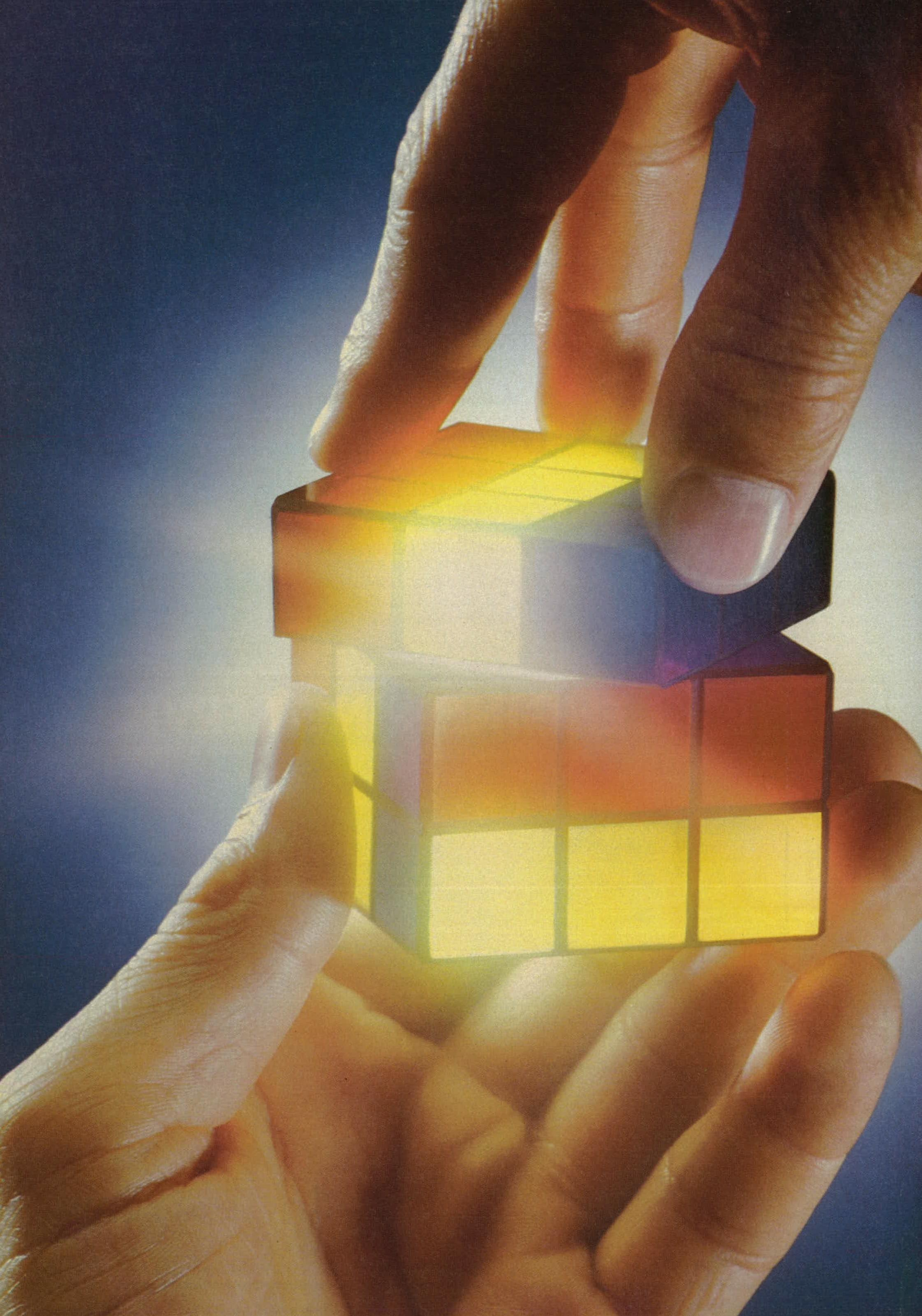
With no mode-locker in the resonator, the Tm,Ho:YLF laser produced 220 mW of CW power at 2.063 micrometers when pumped with 2.6 W of diode power. Mode-locked average power was 100 mW. This represents a wall-plug efficiency of 1% based on 26% wall-plug efficiency for the diode laser, and not including cooling or modulation powers. Mode-locked pulsewidth was 370 picoseconds based on a Gaussian fit to measured autocorrelation values. Long-term stability was excellent, with mode-locking maintained for more than an hour without any adjustments to resonator length or modulation frequency.

The all-solid-state nature of this laser makes it amenable to practical applications. Room-temperature operation makes cooling requirements minimal. The entire device, including the diode pump laser, easily fits on a 2 X 4-foot optical table. Additional packaging and use of a folded resonator could further reduce the laser's overall size. Finally, direct diode pumping of the laser crystal resulted in high amplitude stability, simple setup, and a room-temperature wall-plug efficiency (1%) orders of magnitude higher than previously demonstrated with Kr-ion or Ar-ion/Ti:sapphire pump lasers.

This work was performed by Kenneth L. Schepler and Brian D. Smith at **Wright Laboratory (WL/ELOS)**, *Wright-Patterson Air Force Base, Ohio, and by Frank Heine of Universität Hamburg, Germany, with support from Wright Laboratory and the Air Force Office of Scientific Research.*

Inquiries concerning detailed information on this device and possibilities for commercialization should be addressed to Dr. Kenneth L. Schepler, USAF Wright Laboratory (WL/ELOS), 2700 D Street, Suite 2, Wright-Patterson AFB, Ohio 45433-7405.

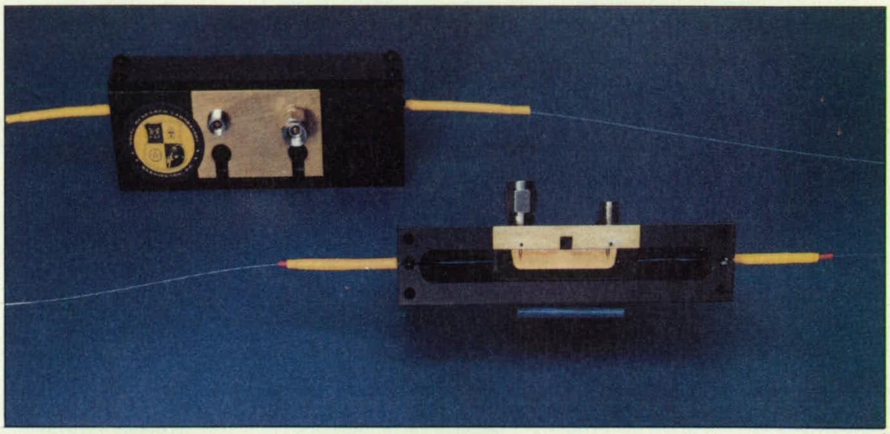
For More Information Write In No. 411



40-Gigahertz External Modulators and Microwave Links

New techniques in velocity matching yield high-performance lithium niobate modulators.

Naval Research Laboratory, Washington, D.C.



Packaged broadband **Lithium Niobate Modulators.**

A $LiNbO_3$ external modulator has been developed with usable optical response out to 40 GHz and beyond with a very low drive voltage of -5 VDC. These broadband devices can be used in microwave fiber optic links with low insertion loss to reach a previously inaccessible frequency regime.

Advantages of these devices include:

- Response of -8 dB (electrical power) at 40 GHz;
- DC drive voltages of 4-5 V;
- optical insertion loss of 7-10 dB;
- operation at 1.3 or 1.5 micrometers;
- advantages of lightweight fiber optics for microwave links to 40 GHz;
- fully packaged device has been demonstrated.

The operating bandwidth of a $LiNbO_3$ Mach-Zehnder interferometer has been extended by achieving a phase match between optical and microwave guided waves. This was accomplished by using a combination of a thick buffer layer and a thick electroplated electrode structure, and by eliminating leakage to substrate modes. A coplanar waveguide (CPW) electrode structure is used to form a microwave waveguide on the lithium niobate surface with a microwave effective index very close to that of the optical effective index in the Ti-diffused optical waveguide. A 0.9-µm SiO_2 buffer layer is used, with a ~16-µm-thick gold electrode. Leakage to substrate modes is prevented by control of the substrate thickness to avoid radiation modes. Since there is little response degradation due to phase mismatch, longer device structures can be employed to reduce the drive voltage. In this case an electrode length of 24 mm yielded a very low DC half-wave voltage (4-5 V). Device impedance is ~35Ω.

These devices have been fiber-coupled and packaged, and are being used in demonstration experiments. Microwave connection is by Wiltron K connectors, and optical connection by FCPC keyed connectors. Further performance improvements appear to be available in bandwidth, impedance match, and optical insertion loss.

These devices open up a new frequency range for fiber optic links previously unavailable to either directly modulated lasers or low-V_π external modulators. Applications include microwave links, delay lines, antenna remoting, optical down-conversion, and so forth.

This work was carried out in the Optical Sciences Division of the **Naval Research Laboratory**. *Patents are pending. For information on rights and licenses contact W.K. Burns, Code 5670; (202) 767-4928. Inquiries concerning rights may also be addressed to Dr. Richard Rein, Technology Transfer Office, Code 1004, Naval Research Laboratory, Washington, D.C. 20375-5320; (202) 767-3744.*

Simplified Generation of Distance Images

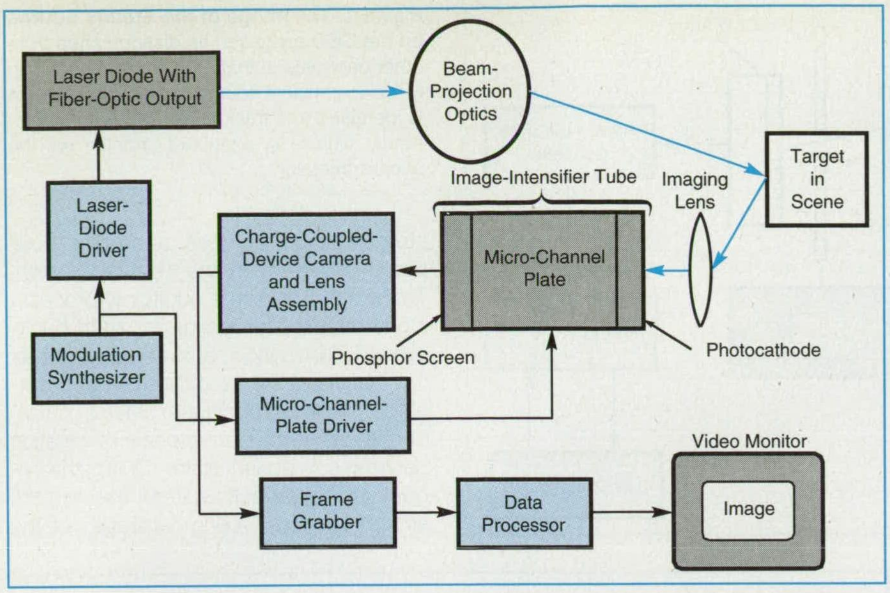
Distances to objects would be indicated by their brightnesses in processed images.

Lyndon B. Johnson Space Center, Houston, Texas

An optoelectronic apparatus that is undergoing development is intended to produce digitized images that contain three-dimensional information: the brightness of each picture element in a digitized image would depend, in a known way, on the distance from the apparatus to the corresponding location in the scene. Unlike older three-dimensional-imaging apparatuses, this one would not contain mechanical scanners. Furthermore, the signal-processing circuitry in this apparatus would be simpler. Thus the new apparatus would be smaller, weigh less, and consume less power. Potential applications include automated inspection, remote exploration, robotic manipulators, robotic vehicles, and maneuvering and docking systems.

The simplification of signal-processing electronics would be achieved by use of a homodyne process on a focal plane to extract the raw distance information from the round-trip delay of radio-frequency amplitude modulation on an optical signal. The apparatus (see figure) would include a laser diode that would illuminate the scene. Light reflected from the scene would be focused on the input plane of an image-intensifier tube. Both the amplitude of light emitted by the laser diode and the gain of the image-intensifier tube would be modulated by the same periodic signal.

The mixing of the two modulated signals in the image intensifier would cause the brightness at each point of the output plane of the image intensifier to include a DC Fourier component proportional to the sine of the difference between the phase of the modulation of the light emerging from the laser diode and the phase of the light returned to the image intensifier from the corresponding point in the scene. This phase difference would be proportional to the time of a round trip of the optical signal, and thus proportional to the distance between the apparatus and the point in the scene. As a result, the output of the image intensifier would be a raw phase-shift or distance image. The



This **Distance-Imaging Apparatus** is based partly on an optoelectronic homodyne principle, which enables simplification of the signal-processing circuitry.

local brightness of the image would be a function not only of distance but also of solar background illumination and variations in local reflectivity in the scene.

Therefore, further processing would be needed to extract the distance information. For this purpose, the raw image would be viewed by a charge-coupled-device video camera, digitized, and processed digitally by an algorithm that would include corrections for the solar background and variations in reflectivity. Data for these corrections would be obtained by making two calibration images of the scene: one with solar illumination only, the other with solar plus unmodulated laser illumination.

This work was done by Karl Wesolowicz, Charles Lewis, Scott Strodtman, and David Dilworth of Daedalus Enterprises Inc., for **Johnson Space Center**. *For further information,* ***write in 137*** *on the Reader Request Card. MSC-22135*

Tracking Steady Light Sources Amid Luminous Transients

Tracking can be done with limited data-processing resources.

NASA's Jet Propulsion Laboratory, Pasadena, California

The Transient Event Rejection for Acquisition and Tracking (TERAT) algorithm governs the operation of the image-data-acquisition and -processing system illustrated schematically in Figure 1. TERAT processes the digitized image data to acquire (that is, identify) a candidate steady source of light, validate the candidate source, and track the validated source, all in the presence of real or apparent luminous transients represented in the image data. The source of light to be tracked could be, for example, a star or a distant luminous beacon. The transients could be caused, for example, by impacts of ionizing radiation on the imaging array of photodetectors or by unsteady light sources that are not meant to be tracked.

TERAT can function with limited data-processing resources. The principal advantage of TERAT is that it can acquire and track a light source quickly, with a high degree of confidence, without knowledge of the direction of motion of the source, without velocity filtering, and without supervision or ancillary input from an external data-processing system. (However, if additional data-processing resources are available, then direction and/or velocity filtering can be used to enhance the result.)

The charge-coupled-device (CCD) imaging array contains a field of view often consisting of hundreds of thousands of pixels. To promote speed in processing and accommodate the limitations of the microprocessor, TERAT operates on only a subset of the field of view, called an acquisition band, at any given time. TERAT proceeds from one acquisition band to the next until a candidate light source is

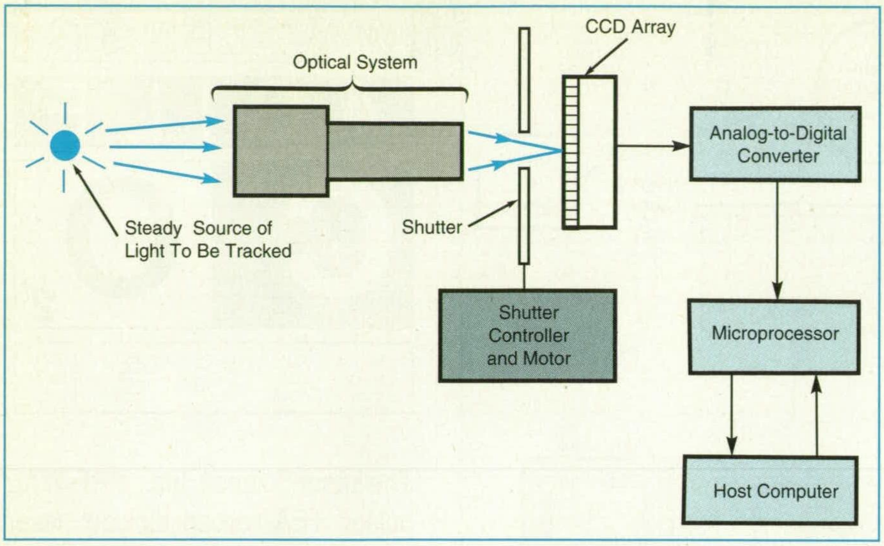


Figure 1. The **Image of the Steady Source** on the CCD array can be distinguished from other phenomena that are or that electronically mimic transient sources of light. The source is identified and tracked by the TERAT algorithm, which is executed mostly on the microprocessor.

found or until it has crossed the entire field of view, in which case it repeats the sequence until it identifies a candidate source.

The operation of the system under TERAT is characterized by interconnected repeating sequences of states, as illustrated in Figure 2. Each state represents a sequence of steps that the microprocessor takes about 100 msec to execute. Transitions between states are defined by transition rules. Initially, the system enters the power-up state, then proceeds to the self-test state. Then it enters the bright-object-test state, wherein it searches for excessively bright sources in the scene and closes the shutter, if necessary, to protect the CCD. The bright-object test is repeated until the brightness in the scene recedes enough to make it safe to open the shutter.

If no excessively bright source is detected during the latest bright-object test, the system proceeds to the first acquisition state, in which it searches for and saves the centroids of groups of pixels brighter than a preset threshold. If such groups are found, the system proceeds to the second acquisition state; otherwise, it returns to the bright-object-test state. In the second acquisition state, the system again acquires centroids as in the first state, then compares the newer set of centroids with those acquired during the first acquisition state. A match is considered to be found when a centroid in the second set lies within a small window (typically, 5 by 5 pixels) of a centroid in the first set. If no match is found, the system returns to the bright-object-test state.

If a match is found, the system proceeds through a sequence of handoff states, which process a smaller pixel patch centered on the centroid match. The system performs additional processing to account for real or apparent background illumination, and to verify further the identity of the candidate group of pixels by imposing additional criteria of size, brightness, and consistency of location between subsequent states. During the sequence of handoff states, the system accumulates a rolling average of the

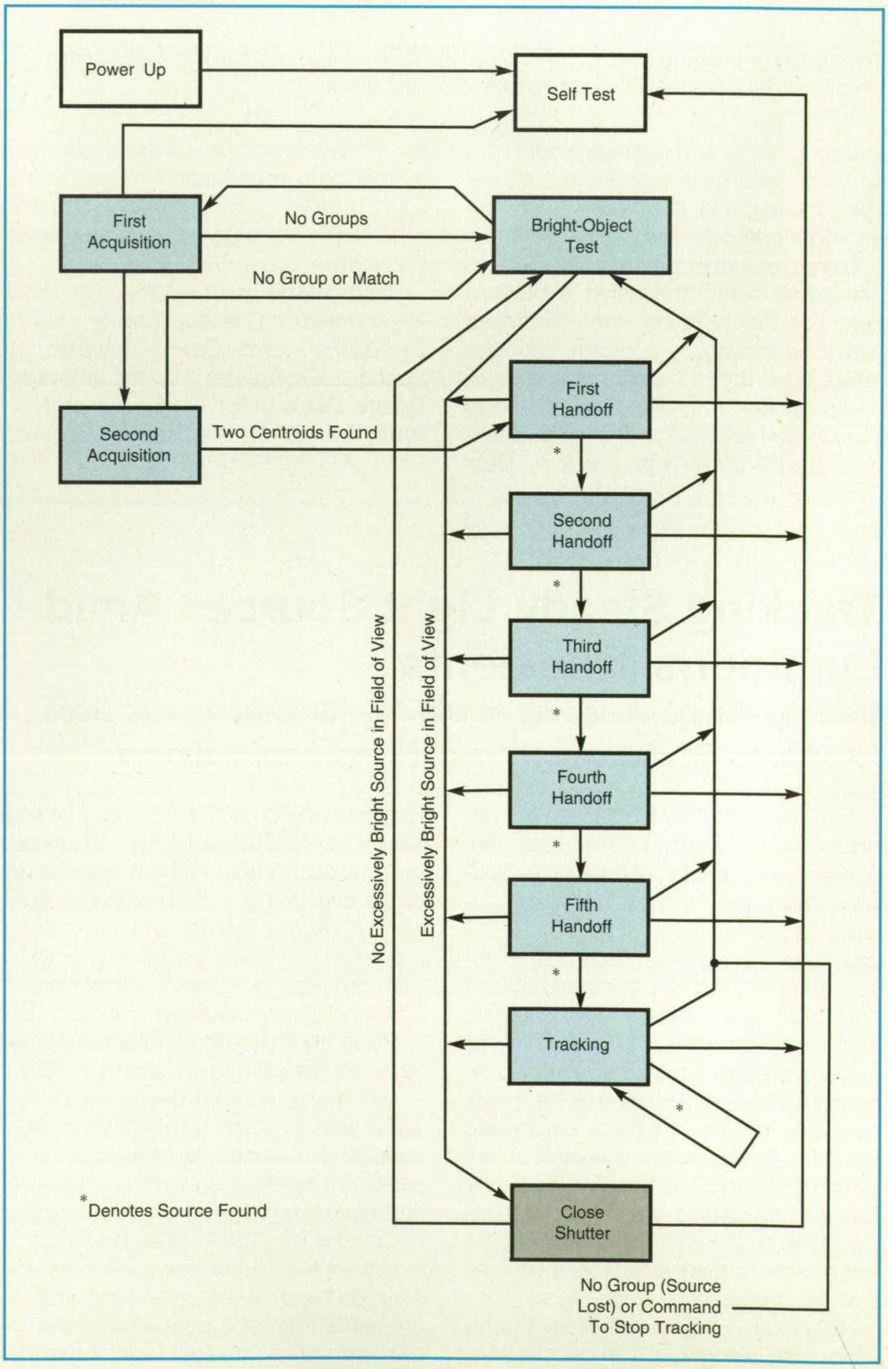


Figure 2. This **State Diagram** summarizes the sequence of operations of the system of Figure 1 under control by the TERAT algorithm.

total brightness of the candidate group of pixels.

If the candidate group of pixels survives the fifth handoff state, the system enters the tracking state, in which it repeatedly tests to determine whether the candidate group of pixels satisfies the size criteria, lies within a specified radius of its previous location, and has brightness within a specified range of the rolling average, in which case the brightness of the group is used to update the rolling average and its position is used as the position for the next such test. If the group fails to satisfy one or more criteria, the test is repeated under modified criteria; if no valid group is found after 10 such tests, the system returns to the bright-object-test state.

The TERAT algorithm is currently operational on NASA's TOPEX mission.

This work was done by Frank Kissh, Walter Fowski, Kenneth Miklus, Rene Abreu, Kenneth Bolin, and David Flynn of Hughes Danbury Optical Systems, Inc., for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 139*** *on the Reader Request Card.*

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457(f)], to the Hughes Aircraft Co. Inquiries concerning licenses for its commercial use should be addressed to

Patents & Licensing
Hughes Danbury Optical Systems
c/o Hughes Aircraft Co.
7200 Hughes Terrace
Los Angeles, CA 90080-0028

Refer to NPO-19027, volume and number of this Laser Tech Briefs *issue, and the page number.*

Optical-Correlator Neural Network Based on Neocognitron

Patterns can be recognized, with allowances made for shifts in sizes and aspect angles.

NASA's Jet Propulsion Laboratory, Pasadena, California

A multichannel optical correlator implements a shift-invariant, high-discrimination pattern-recognizing neural network based on the paradigm of the neocognitron (see Figure 1). An optical correlator was selected as the basic building block of this neural network because invariance under shifts is an inherent advantage of the Fourier optics that are included in optical correlators in general.

Multilayer processing is achieved in this system by iteratively feeding back the output of a feature correlator to an input spatial light modulator and updating Fourier filters. The neural network is trained by use of characteristic features extracted from target images. The multichannel implementation enables the parallel (that is, simultaneous) processing of a large number of selected features. Accordingly, this system operates on collections of features instead of on a template, as in other systems. Simple and elementary features of an input pattern are first recognized in the first layer of processing. Extracted features are then recombined into more complicated ones and are subsequently recognized in a deeper layer. This process is continued until the recognition and classification are completed, and the results are displayed in the output layer.

The input image, possibly containing subimages of multiple targets to be recognized and/or discriminated, is fed into

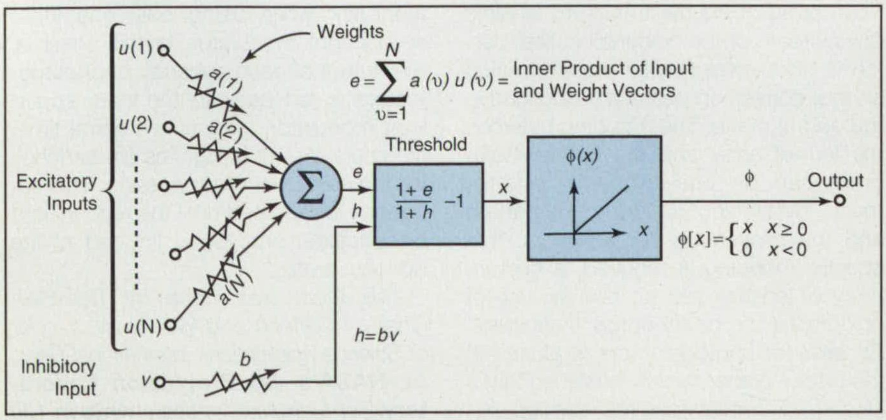


Figure 1. The **Neocognitron Includes Cells** called "S cells," one of which is illustrated here schematically. The neocognitron is a conceptual electronic neural-network model for the recognition of visual patterns.

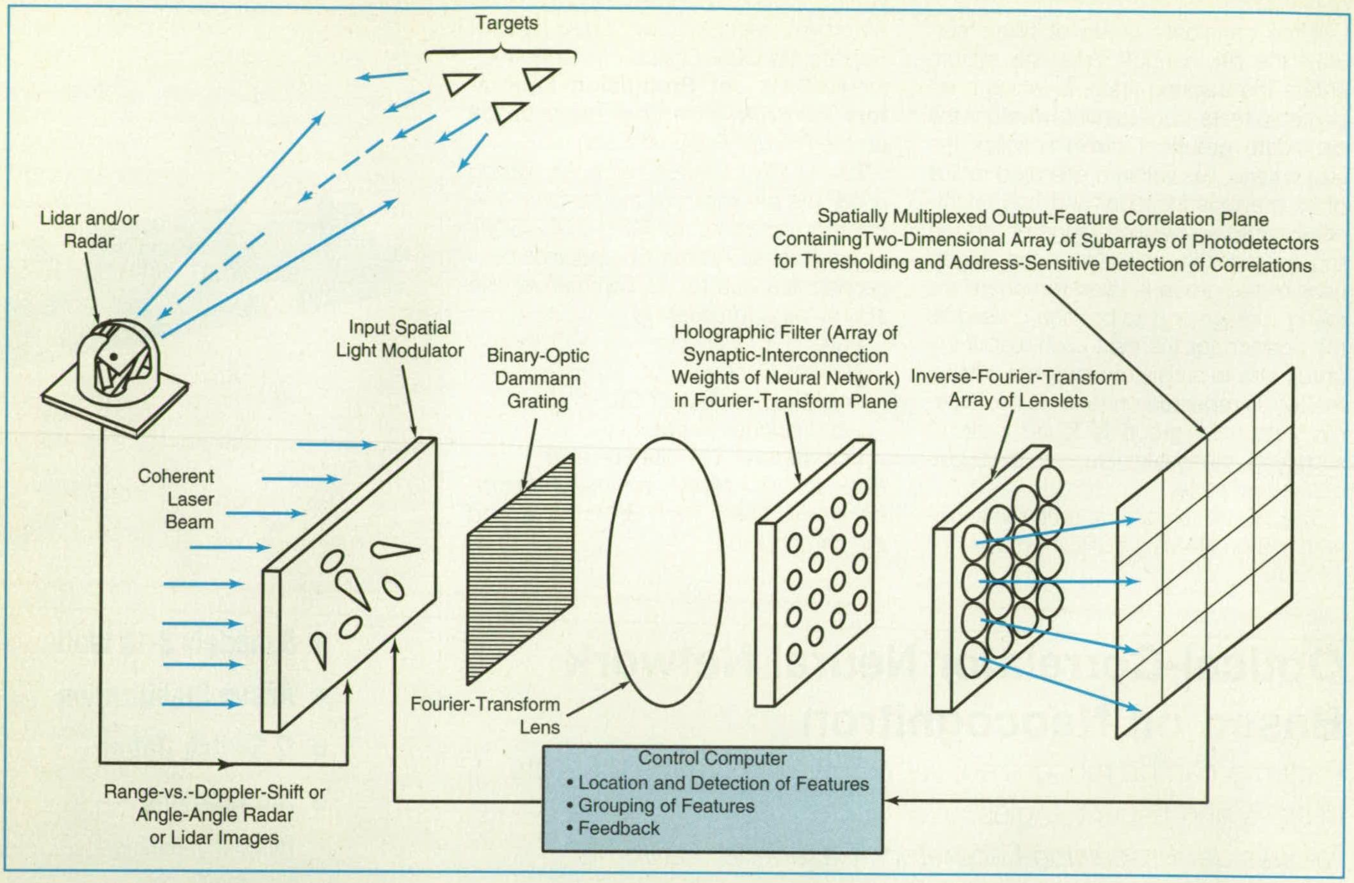


Figure 2. This **Multichannel Optical Correlator** implements a shift-invariant pattern-recognizing neural network with multilayer processing effected via time-multiplexed feedback.

an input spatial light modulator of the multichannel correlator (see Figure 2). A binary Dammann diffraction grating [fabricated in poly(methyl methacrylate) by electron-beam lithography] and a Fourier-transform lens are used to generate an $N \times N$ array of spatially replicated Fourier spectra of the input image. A holographic filter in the Fourier-transform plane performs matched spatial filtering between the input and selected characteristic features. This holographic filter plays the role of the array of synaptic-interconnection weights of the neural network.

An array of Fourier-transform lenslets downstream of the holographic filter performs an inverse Fourier transformation so that correlation peaks are obtained in the output plane. The mapping between the lenslet array and the Fourier hologram can be one-to-one or one-to-many, depending on the input pattern and the processing requirements. If a specific mapping is required, a custom array of lenslets can be built by use of holographic or binary-optics techniques. An array of photodetectors is placed in the output plane of each lenslet so that a cluster of spatial features can be extracted from the input pattern and converted into the corresponding cluster of correlation peaks.

Thus, the multichannel correlator processes the input image into a cluster of feature-correlation peaks. Each cluster is simultaneously detected and thresholded by a different subarray of the array of photodetectors. In the case of a complicated input pattern, a single pass of the multichannel correlator may not be adequate to complete the entire recognition/classification process: it could be necessary to pass the feature-correlation patterns along for the second layer of processing. A time-multiplexing scheme makes it possible to accomplish such feedback while using only one input spatial light modulator. In this scheme, the output of each subarray of photodetectors is fed back to the input spatial light modulator, and, at the same time, the neural-weight holograms are switched for the next layer of processing. This sequence is repeated until the recognition/classification process is finished at the deepest level.

This work was done by Tien-Hsin Chao of Caltech and William W. Stoner of Science Applications International Corp. for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 130*** *on the Reader Request Card.*
NPO-18988

Detecting Leaks With an Infrared Camera

A nondestructive test would make removal of insulation unnecessary.

Marshall Space Flight Center, Alabama

A proposed test would reveal a small leak in a gas pipe — for example, a leak through a fatigue crack induced by vibration — even though insulation covers the pipe. An infrared-sensitive video camera would be aimed at the part(s) containing the suspected leak(s). The insulated pipe would be pressurized with a gas that absorbs infrared light. If a crack were present, the escaping gas would travel along the outside of the pipe until it reached the edge of the insulation. The gas emerging from the edge of the insulation would appear as a dark cloud in the video image.

The rate of leakage could be quantified from the size of the cloud. If the rate were found to be great enough, the insulation could then be removed and the pipe repaired. If the leak were acceptably small, then the difficulty, time, and cost of removal and replacement of insulation could be avoided.

This work was done by Barry P. Easter and Alfred P. Steffins, Jr., of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information,* ***write in 155*** *on the Reader Request Card.*

MFS-29892

Ultra-High-Performance Cathode Ray Tube

Innovative balun design permits single-transient measurements above 32 GHz.

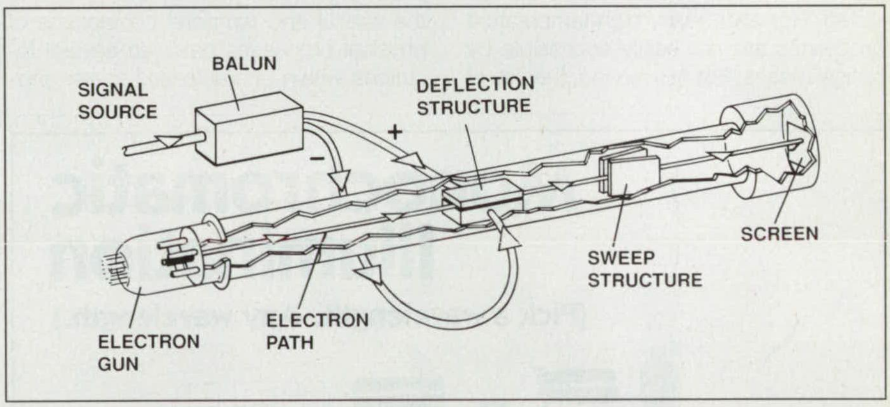
EG&G Energy Measurements Inc., Las Vegas, Nevada

A team of scientists and engineers has developed an ultra-high-performance cathode-ray tube (CRT) that measures extremely rapid electronic signals extending into the microwave region. The device's novel physical arrangement eliminates the distortion that had plagued earlier systems, allowing the study of once unobservable electrical signals with a minimum of postprocessing.

The project began with a request from Lawrence Livermore and Los Alamos National Laboratories that EG&G Energy Measurements build and field a prototype. The team delivered a CRT capable of measuring single-transient signals with frequencies higher than 10 GHz at the industry-standard bandwidth of -3 dB. The amplitude/frequency rolloff was gentle enough that transient 20-GHz signals could be observed. The current prototype is capable of single-transient measurements of up to 32 GHz.

In the design, the balun feeds a double-ended (two-mirror-image) structure, dividing the signal in half and inverting the polarity of one side of it (see figure). The two signals, one positive and one negative, form a virtual ground between the structures, preserving the characteristic impedance and providing a much more uniform deflection field.

The device measures signals much less than 30 picoseconds long, approaching the time domain of importance to chemical reactions. It can sense a 250-mV or stronger signal from such reactions and other phenomena. The lower sensitivity that results from high-bandwidth design can be improved with a commercial amplifier. To further increase sensitivity, the scientists installed an in-bottle (that is, inside the CRT vacuum) high-resolution charge-coupled display that replaces the screen phosphor and digitizes the signal data, eliminating the need for external cameras or film.



The electron gun on the left end of the **Cathode-ray Tube** creates a beam of electronics that travels along the tube, passing through the deflection and sweep structures. An incoming signal enters the balun and moves on to the deflection structure, where it meets the electron beam. In that instant, the beam is deflected on down the tube in proportion to the size of the signal. The sweep structure then steadily moves the beam across the phosphor face of the tube, creating a graph of the signal.

Because the original design suffered from considerable internal jitter (the nonstability of display caused by either the oscilloscope or the source as a pulse moves around on the baseline), the team developed a new triggering circuit that reduces such jitter to 5 picoseconds. The result is a steady display and the ability to observe a continuous stream of pulses as well as single shots.

Ultra-high-performance (UHP) CRT technology is useful in any program that requires the recording of fast-transient electronic signals, including laser and nuclear-fusion research. It can also measure the pulse power of particle devices. The new system has been used to verify the performance of EG&G's linear accelerator, representing the first accurate electronic recording of a single accelerator pulse 35 picoseconds wide.

EG&G uses oscilloscopes to characterize the bunch length of the accelera-

tor's output. In order to measure bunch length electronically, scientists would normally have to fire the accelerator about 5,000 times to achieve an average display. For devices activated by a single bunch, there is no one-to-one correlation between the bunch stimulating the device and the bunch average given by the sampling oscilloscope. The UHP CRT can measure the single bunch.

The National Institute of Standards and Technology is considering the UHP CRT for developing standards that require high-bandwidth measurements. Communications and radar are other examples of areas that may be able to use the UHP CRT to collect information more detailed than is currently possible. For instance, the detailed structure of a single radar chirp may be observed without the need for sampling a large number of repetitive chirps. This could have advantages in diagnostics and in detection vulnerability reduction.

The work was done by **EG&G Energy Measurements, Inc.** *under contract to the Department of Energy by Chris Hagen, John Champeny, Michael Gruchalla, Chuck Hudson, Stan Kocimski, William Kuhlow, Richard Mobley, Neil Norris, Mark Prokop, Jerome Spector, and James Thomas. EG&G is seeking partners for commercial cooperative ventures. For more information concerning the commercial use of this invention, including patent status and availability of rights and licenses, contact Bruce Whitcomb at EG&G's Las Vegas Operations; (702) 295-3164.*

Fiber Optic Switch for Broadband Emission Spectroscopy

An array of fibers is used to observe a plasma in an arc jet.

Lewis Research Center, Cleveland, Ohio

Emission spectroscopy is a technique commonly used to improve understanding of high-temperature phenomena. High-temperature processes emit radiation, which provides information about the process and about the internal states of elementary particles that participate in the processes. When sufficient optical access is available, light can easily be collected. However, many high-temperature processes are not easily accessible by optical means. For this reason, the use of optical fibers for collection and transport of emitted light has become popular. Coupling of light from a fiber into a spectrometer or monochromator with matching of numerical apertures and optimization of throughput is a standard procedure.

Many high-temperature processes comprise large-scale phenomena. Studying the spatial and temporal correlations of physical processes between several locations within characteristic scales provides desired information on macroscopic physical processes. This can be achieved with emission spectroscopy by use of multiple optical fibers. Simultaneous coupling of light from these fibers into a single available spectrometer and/or monochromator cannot be accomplished without the added expense of a two-dimensional array and increased complexity of calibration. Quasi-simultaneous coupling, while maintaining optimum alignment and maximum throughput of the broadband emission, can be achieved by use of the instrument shown schematically in the figure. This instrument, referred to as the fiber optic multiscanner, has been used successfully in the study of the frozen-flow losses internal to the flow of plasma inside the nozzle of an arc jet.

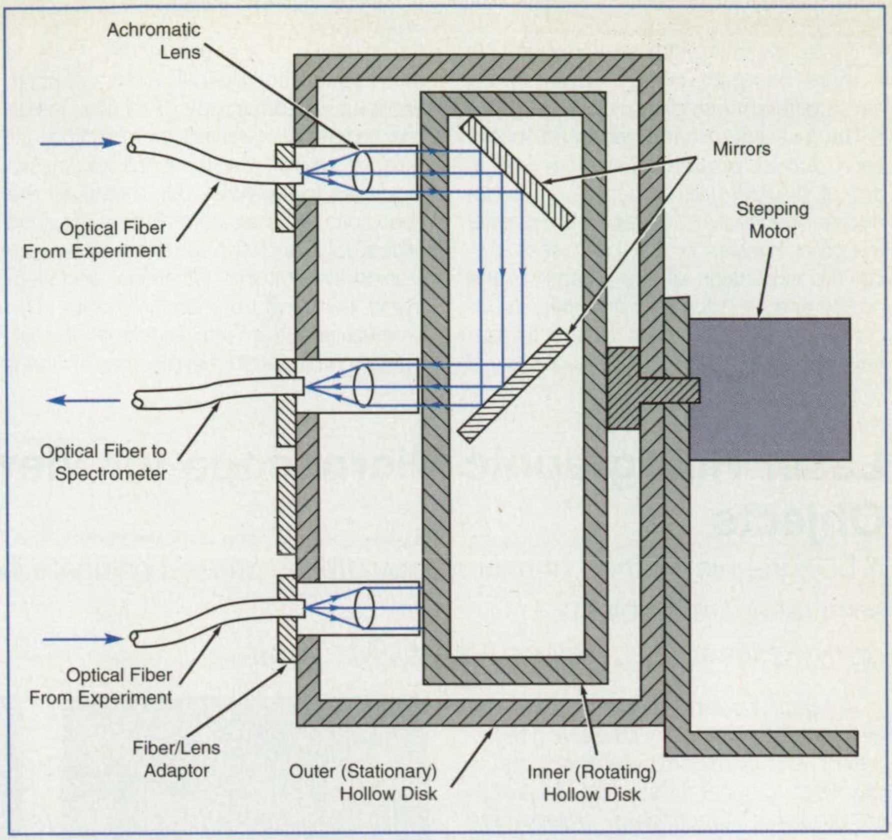
The instrument includes two hollow disks of different sizes, and a stepping motor. There is a hole in the center of the front faceplate of the larger hollow disk, and a number of equal-diameter holes are placed around its circumference. Each hole accommodates a fiber/lens adaptor. A fiber optic connector (for example, SMA 905/906 or equivalent) can be mounted in a fixture on the front of each adaptor. An achromatic lens is mounted inside each adaptor; its location can be adjusted such that the light that emerges from a fiber that has a given numerical aperture is collimated at the design wavelength, with extremely small deviations at off-design wavelengths.

The smaller hollow disk is mounted inside the larger one. Its outside diameter virtually matches the inside diameter of the larger disk. The front faceplate of the smaller disk contains two holes with diameter equal to the inner diameter of a fiber/lens adaptor. One hole is positioned concentrically against the central adaptor. The other hole is on the periphery and can be placed concentrically with any of the outer adaptors. Two mirrors

are placed on the backplate of the inner disk and on the centerlines of the two holes at an angle of 45°.

The inner disk is mounted on the axis of the stepping motor. As this disk turns, the central mirror remains aligned with the central adaptor. This central adaptor is used to couple light through a single fiber to the spectrometer. An array of fibers can be mounted on the outer adaptors. By rotating the inner disk to align the peripheral hole with the adaptor of a designated fiber in the array, the output of that fiber can be coupled to the spectrometer. The stepping motor can be programmed to scan a certain set of fiber outputs. The selection or sequence of outputs can be changed easily. Tight tolerances and rubber sleeves are used to minimize stray light.

Laboratory tests of a prototype show that a throughput efficiency of more than 75 percent can be obtained with a repeatability of 0.1 percent, demonstrating that extremely repeatable alignment can be obtained for each fiber. If the level of light is not a critical consideration, this instrument is ideal for coupling of light from multiple optical fibers into a spectrometer. The time needed to switch between fibers is 0.3 second for the current prototype, with 13 fibers installed in



The **Inner Disk Is Rotated** by the stepping motor to align the peripheral hole in the outer disk with one of the fiber/lens adaptors.

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it. Faster switching can be achieved with a more compact design (fewer fibers) and a different stepping motor.

The instrument has been used to observe arc-jet plasmas. Power is lost in arc-jet thrustors via two major mechanisms: one involves losses to the anode; the other involves frozen-flow losses during the expansion of the plasma in the nozzle and the plume. A first step in understanding the physics of the frozen-flow losses is to study the evolution of the plasma during expansion. Outside the nozzle, easy optical access enables emission spectroscopy. The flow inside the nozzle is observed by drilling small holes at several axial locations and inserting fibers in the holes. By means of the fiber-optic scanner, each fiber is scanned repeatedly and the emitted spectrum studied for rotational, vibrational, and electronic temperature measurements. The emitted spectrum studied is in the ultraviolet: this excludes the use of fibers for measurements of low-intensity light, usually at the downstream end of the nozzle, inasmuch as optical fibers attenuate ultraviolet light severely. This instrument performs well where sufficient light is emitted.

This work was done by Wim de Groot and Roger Myers of Sverdrup Technology Inc. and Dieter Zube of Stuttgart University for **Lewis Research Center**. *No further documentation is available.*
LEW-15600

Laser Holographic Microscope for Viewing Transparent Objects

A holographic method of microscopy utilizes phase-conjugate illumination of transparent and semitransparent objects.

Army Research Laboratory, Adelphi, Maryland

A team of scientists has developed a new form of microscopy for viewing transparent and semitransparent objects. It promises to generate solutions to practical problems in technology areas where present methods are inadequate, such as phase-shifting masks for photolithography and diffractive optical elements. The conventional technique for monitoring phase structures in these areas is differential interference contrast (DIC), which does not produce sufficient contrast when visualizing small retardations in phase. The new method allows the imaging of phase-shifting structures with considerably greater sensitivity.

The new microscope, the laser holographic microscope (LHM), is based on a method of generating a special light beam for transilluminating the object. In the LHM the object is illuminated by a holographic reconstruction of the coherent light transmitted through the object. The reconstructed light differs, however, from the original transmitted light in that the phase fronts are inverted: that is, the illumination is phase-conjugate. The LHM images are digitally processed for improved quality. But the times required to create holograms and process the image are short, so an image can be viewed in close to real time.

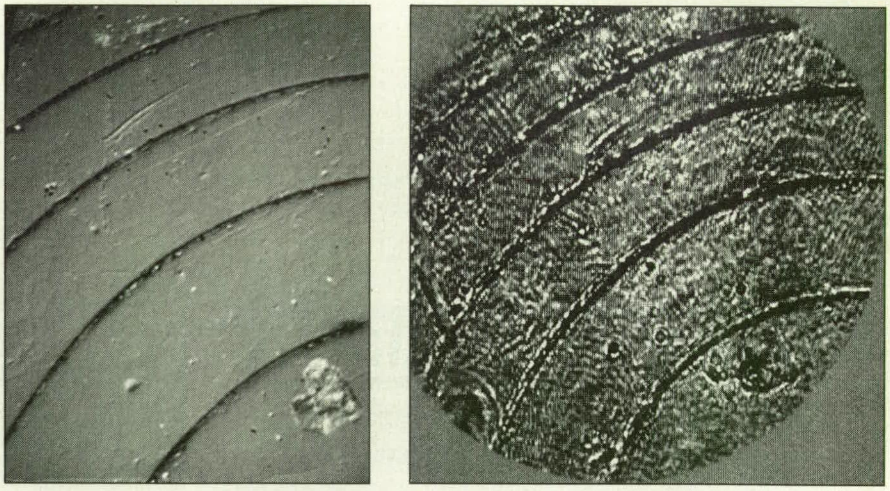


Figure 1. A **DIC Image (left) and an LHM Image** of a center section of a diamond-turned diffractive lens.

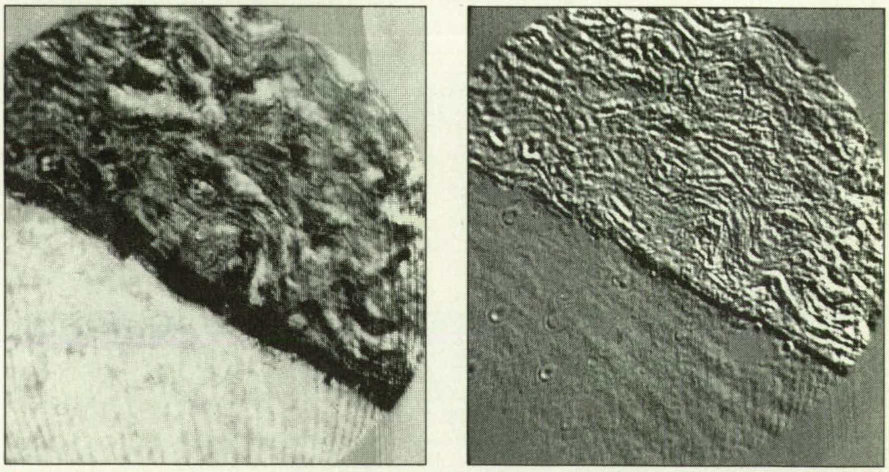


Figure 2. **LHM Images** of a stained tissue section of an ovarian cyst: at left, intensity variations are visible; at right, a phase-contrast image.

Figure 1 shows images of a center section of a diamond-turned diffractive lens. This is a cast Fresnel lens with convex annular-ring sections rising in sawtooth fashion. The relative phase shift between minimum and maximum thickness is 2 π. On the left is a DIC image, on the right an LHM image. These may be viewed as if they were moonscapes with glancing illumination from the upper right. Although both images show the ridges, only that from the new microscope shows the fine structure of the surface, generated by the diamond-turning tool when forming the mold that was used to cast the lens. The images are about 0.5 mm across.

The new microscopy also produces important improvements in image quality

and detail in biomedical imaging. In Figure 2, a bright-field LHM image of a stained tissue section of an ovarian cyst is shown at left. The image shows intensity variations produced by selective staining and is similar to an ordinary microscope bright-field image. Ordinary laser light can also be used to produce bright-field images, but these are always of poor quality compared to those produced with the new microscope, which uses phase-conjugate illumination. The LHM can also produce the phase-contrast image shown at the right of Figure 2. The images are 140 µm (0.14 mm) in diameter.

Because of its ability to minimize the effects of phase detail in bright-field images, the LHM has the ability to image opaque objects in a translucent or diffusive medium. In an experiment, brine shrimp, opaque spheres about 0.1 mm in diameter, were embedded in a diffusing waxy material. Figure 3 shows images produced when the specimen slide is transilluminated both by incoherent illumination (left) and coherent phase-conjugate illumination (right). In the laser holographic bright-field image, the diffusing effects of the medium are minimized, producing clear images of the spheres. This is in contrast to the incoherent-light image on the left, where the distorting effects of the medium obscure detail. The LHM, a major evolution in optical microscopy, is expected to affect many areas.

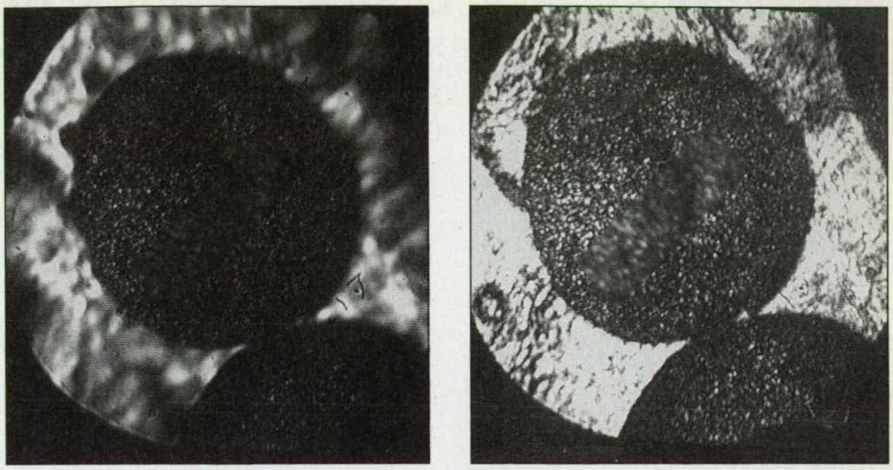


Figure 3. Spherical opaque brine shrimp about 0.1 mm in diameter and embedded in a diffusing waxy material: left, transilluminated by incoherent light and, right, by **Coherent Phase-Conjugate Illumination**.

This work was done by the Radiation Effects Branch, Nuclear/Directed Energy Division of the **Army Research Laboratory**. *Inquiries concerning this technology should be addressed to Director, U.S. Army Research Laboratory, Att: AMSRL-CP-TA (Norma Vaught), 2800 Powder Mill Rd., Adelphi, MD 20783-1145; (301) 394-2952.*

Rapid Nonsurgical Optical Detection of Esophageal Cancer

A nonsurgical biopsy technique for diagnosing esophageal cancers has been developed and tested successfully.

Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee

A laser-based nonsurgical biopsy technique has been developed for quickly diagnosing certain cancers, such as those of the esophagus. The method informally has been dubbed an "optical biopsy" because only light is used to determine malignancy. No tissue has to be removed from the patient, as is the case with conventional surgical biopsy, and the diagnosis is made almost instantly. This new laser procedure not only reduces physical trauma to the patient, but also drastically reduces the time a patient and doctor must wait to obtain biopsy results, which can be several days or weeks. The new procedure also should help reduce significantly health-care costs associated with certain cancer diagnostics and therapies.

A study involving more than 200 measurements on 48 patients at the Thompson Cancer Survival Center in Knoxville, Tennessee, yielded a success rate of nearly 100% for diagnosing normal tissues and malignant tumors of the esophagus. The researchers plan to extend the new techniques to tumors of the colon, cervix, lungs, and urinary bladder.

The technique employs a new endoscopic method that uses laser light to take measurements in less than one second. A new analytical method called differential normalized fluorescence also is used.

The new procedure employs a flexible probe made of 19 optical fibers bundled together. The 2.3-mm probe has a diameter roughly the same as a piece of cooked spaghetti. During the procedure the physician slips the probe into the biopsy channel of an endoscope. (The biopsy channel is normally that part of the instrument through which a pincer-tipped cable is passed to physically remove tissue.)

The bundled optical fibers are divided by function into two groups. One delivers low-energy pulsed light to the suspect tissue when the attending endoscopist lightly touches the area with the tip of the probe. Molecular components of the tissue absorb the laser light and, depending on the wavelength and the nature of the tissue, re-emit it.

A second group of fibers collects this fluorescent light and carries it to a photometric detector and a computer, where it is digitized into fluorescence data and stored for further analysis. A computer monitor displays the spectrum of high and low intensities of the fluorescence.

The procedure reveals a relatively intense signal from normal tissue when compared to the much weaker signal of a malignant tumor. This could indicate that the cancerous tissue lacks certain biological components or has been altered with respect to blood flow, tissue structure, and red-blood-cell absorption by the tissue.

The intensity difference alone, however, is insufficient for diagnosis, because intensity can depend upon nonphysiological factors, such as the distance between the tip of the endoscope and the tissue being examined. To create a more reliable foundation for diagnosis, the researchers devised a new method of spectral analysis to process the fluorescence data. When it is applied to the fluorescence data, tiny spectral differences between normal and malignant tumors are significantly more apparent. These spectral analyses have displayed consistent accuracy in contrast to physical biopsy results.

Reliable real-time diagnosis is the next step, possibly eliminating physical biopsies and time-consuming histopathology tests. The researchers envision the use of "smart lasers" to destroy a tumor immediately following an optical biopsy.

This research was performed by Dr. Tuan Vo-Dinh of **Oak Ridge National Laboratory**, *and Dr. Bergein Overholt and Dr. Masoud Panjehpour of the Thompson Cancer Survival Center. The work was funded by the Thompson Cancer Survival Center, the Thompson Charitable Foundation, and the American Laser Foundation, with the support of the Department of Energy's Office of Health and Environmental Research.*

Inquiries about technical aspects of the procedure, patent status, and possible commercialization opportunities should be addressed to Wayne Scarbrough, Martin Marietta Energy Systems, Inc., P.O. Box 2008, M/S 6266, Oak Ridge, TN 37831; (615) 576-0226.

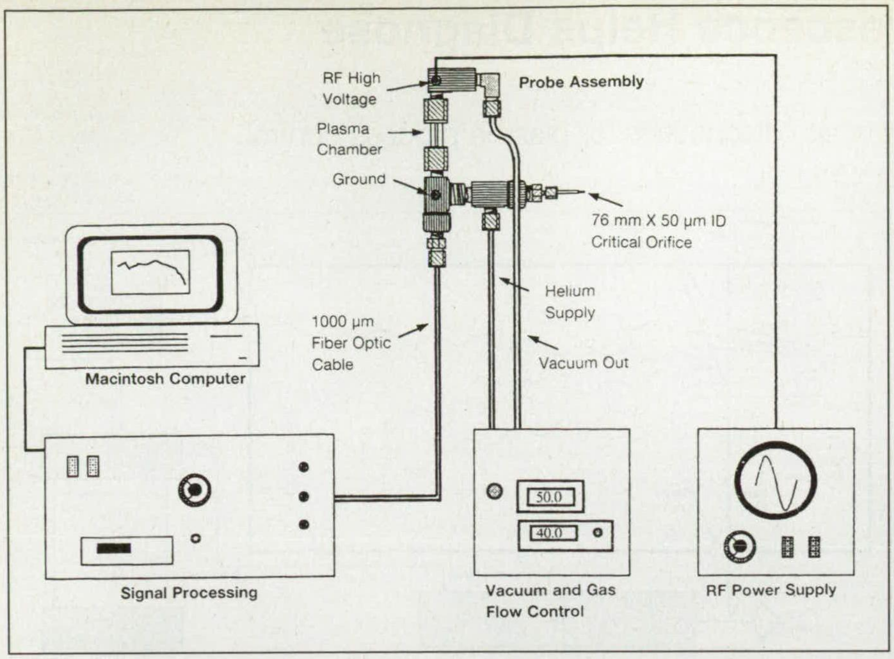
A Spectrochemical Emission Sensor System Detects Chlorinated Compounds

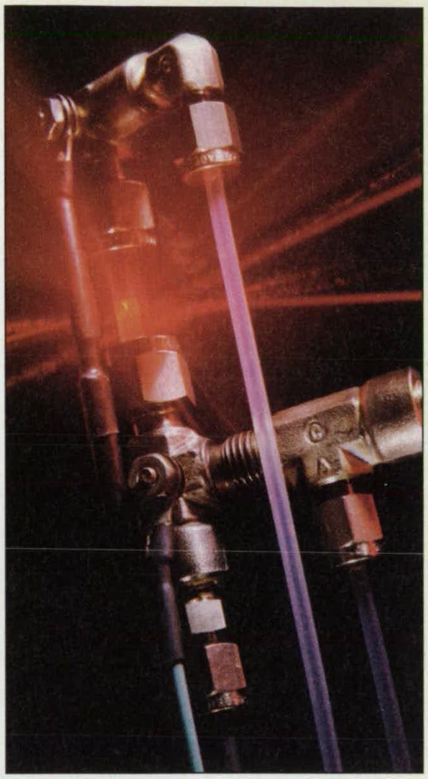
"HaloSnif" provides real-time measurement of volatile chlorinated compounds (VOCs) in air, gases, and water.

Pacific Northwest Laboratory, Richland, Washington

The spectrochemical emission sensor system called "HaloSnif" is being used to provide real-time concentration data for carbon tetrachloride in soil gas during soil vapor extraction at the Hanford Site in southeastern Washington state. Previously, technicians used grab samples and non-real-time systems for monitoring carbon tetrachloride concentrations in extracted soil gas, a procedure that was slow and required large dilutions and continuous attention by the technical staff for high-quality data. HaloSnif, with its real-time monitoring capabilities, wide dynamic operating range, and long-term stability, is expected to increase the quality of the derived data, thereby reducing monitoring costs associated with the project.

HaloSnif is a compound class-specific fiber optic spectrochemical emission sensor system developed and patented by Pacific Northwest Laboratory. The technology is based on the atomic emission of chlorine in a helium plasma. The HaloSnif sensor system uses a critical orifice inlet for air sampling or a heated membrane inlet for water sampling. A helium plasma, sustained by a radio frequency exciter, provides the energy to dissociate and excite the entrained chlorine compounds. A fiber optic cable transmits the optical plasma emission to a signal processing module, where the light is optically filtered for the chlorine emission and amplified. HaloSnif features a detection limit from 1 to 5 ppm, depending on the compound of interest. Its response is linear from the minimum





(Above) Schematic diagram of the HaloSnif **Spectrochemical Emission Sensor System**. (Right) The **HaloSnif** system uses a helium plasma, whose emission is transmitted through a fiber optic cable to a detector, to sense chlorinated solvents.

compound detection limit to 10,000 ppm and is completely reversible when the source of chlorine is removed.

HaloSnif has successfully measured carbon tetrachloride concentrations in soil gas at the Hanford Site VOC Arid Site Emergency Response Action, trichloroethylene in soils at Tinker Air Force Base in Oklahoma City, and trichloroethylene and perchloroethylene in soils at the Department of Energy's Savannah River Site. It has recently been successfully tested as a real-time monitoring tool during cone penetrometer investigations at the Hanford Site. HaloSnif's results clearly identified carbon tetrachloride-contaminated layers in the vadose zone to a depth of 100 feet.

Other applications for which this technology is suited include source, process, or stack monitoring for gaseous chlorinated species in a gas or water stream. HaloSnif can detect the presence of refrigerants (CFCs) or other chlorinated hydrocarbons in air. Thus it is valuable for continuous real-time monitoring of human exposure in facilities where processing involves CFCs or chlorinated solvents. It can be tailored to trigger a threshold alarm, so that dangerous situations can be detected and mitigated in the early stages.

HaloSnif is currently available for demonstration as a transportable two-component field-hardened system. Setup can be accomplished easily in one hour by two people and minimum maintenance is required.

This work was done by Khris B. Olsen and Norman C. Anheier of **Pacific Northwest Laboratory** *for the Department of Energy under contract DE-AC06-76RLO 1830. Inquiries concerning rights for the commercial use of this invention should be addressed to Dr. Mike Lind, Pacific Northwest Laboratory, P.O. Box 999, Richland, WA 99352.*

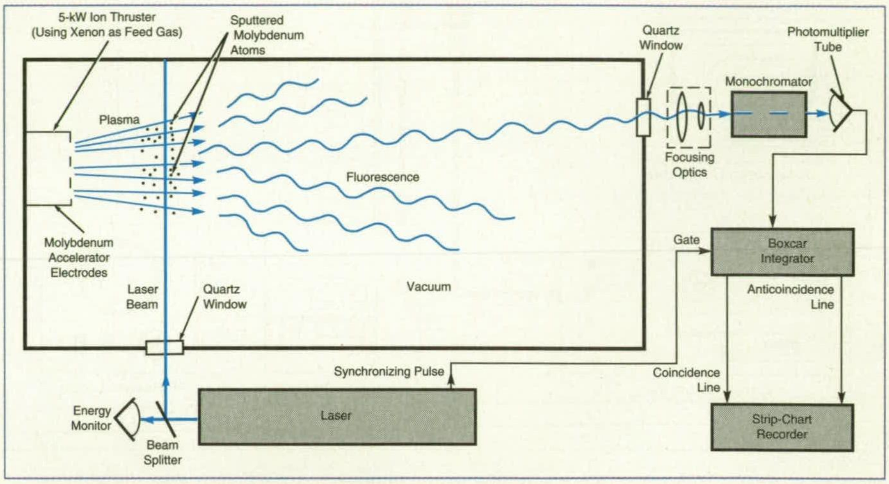
Laser-Induced Fluorescence Helps Diagnose Plasma Processes

The optical technique can provide in situ diagnostics for plasma process control.

Lewis Research Center, Cleveland, Ohio

A technique developed to provide in situ monitoring of rates of ion sputter erosion of accelerator electrodes in ion thrusters can also be used for ground-based applications to monitor, calibrate, and otherwise diagnose plasma processes in the fabrication of electronic and optical devices. The technique involves the use of laser-induced-fluorescence measurements, which can provide information on rates of ion etching, inferred rates of sputter deposition, and concentrations of contaminants.

The figure illustrates schematically the use of laser-induced fluorescence to diagnose ion erosion of a molybdenum accelerator electrode in an ion thruster used for space applications. Some of the sputtered metal atoms downstream of the electrode are illuminated by a tunable dye laser. The laser light, at a wavelength of 390.2 nm, excites a ground-state transition in the molybdenum atoms; the particular transition is selected because it yields the largest fluorescence signal for a given laser power. The level of fluorescence is proportional to the density of the sputtered atoms and therefore to the rate of sputtering. Variations in the level of fluorescence can be correlated with variations in the accelerator electrode voltage, electrode current, background vacuum facility pressure, and other operating



Laser-Induced Fluorescence from excited molybdenum atoms, sputtered from an ion thruster accelerator electrode, gives an indication of the density of metal atoms and therefore the rate of ion sputtering.

conditions. Thus, laser-induced fluorescence provides the means for real-time monitoring of the rate of erosion of the accelerator electrode and facilitates the correlation of changes in the erosion with changes in the performance parameters of the ion thruster. This optical diagnostic can be readily tailored to control critical plasma parameters for fabrication processes involving industrial ion beam or plasma sources.

This work was done by J. R. Beattie, J. N. Mattosian, C. J. Gaeta, R. S. Turley, J. D. Williams, and W. S. Williamson of Hughes Research Laboratories for the Space Propulsion Technology Division, **Lewis Research Center**. *For further information,* ***write in 190*** *on the Reader Request Card.*
LEW-15597

Fiber Optic Sensing System Measures Small Displacements

Interferometry at two modulating frequencies yields results independent of losses in fiber optic links.

Lewis Research Center, Cleveland, Ohio

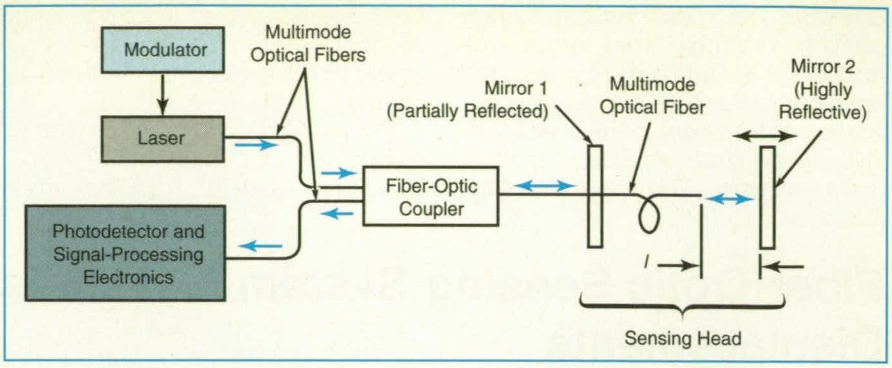
A fiber optic sensing system measures small changes in the intensity of light propagating through its interferometric sensing head. The quantity to be determined using this approach can be a displacement or any other phenomenon that affects the intensity of light. The sensing scheme involves an imbalanced fiber optic interferometer as a sensing head and amplitude modulation and detection at two radio frequencies. One important advantage of this sensing system over prior fiber optic sensors that involve pulse-amplitude modulation is that the length of the imbalance can be shorter.

A schematic diagram of the system to measure small displacements is shown in the figure. The laser light, modulated at the two frequencies, is sent through a fiber optic coupler and along a main multimode optical fiber to mirror 1, which is partially reflective. Part of the light transmitted through mirror 1 enters a loop of multimode optical fiber. The light that emerges from the other end of this fiber travels across a gap to highly reflective mirror 2. This gap is the gap to be measured; that is, mirror 2 is attached to the object, the displacement of which is to be measured. Light reflected from mirror 2 returns through the loop of fiber to mirror 1, where it interferes with light reflected by mirror 1. The resultant signal propagates back along the main optical fiber, through the fiber-optic coupler, to a photodetector. Thus, the sensing head, comprising the mirrors and the fiber loop, constitutes a Fabry-Perot interferometer. A change in the width in the gap affects the amount of light coupled back into the fiber loop upon reflection from the mirror 2. This affects the intensity of the light

propagating in the loop and, consequently, the intensity of the resultant signal that emerges from the interference. A short coherence length of the laser used ensures that the optical interference does not happen and the observed interferometric effects occur at the two modulating radio frequencies.

One of the radio frequencies is selected so that the constructive interference occurs at the given length of the imbalance. The other radio frequency leads to the destructive interference at the same imbalance. Thus one modulating frequency is double the other one.

The detected interference signals at the two frequencies are first processed separately, then the ratio between their amplitudes is computed. This provides common mode rejection and makes the output signal, which is the amplitude ratio, independent of variable intensity losses in the fiber optic links among the laser, sensing head, and photodetector. It results in enhanced system sensitivity and stability.



This **Fiber-Optic Sensor** measures small changes in the distance *l*. The measurement scheme involves interferometry, at two modulation frequencies, between amplitude modulations of portions of the laser beam reflected from mirrors 1 and 2.

Once the contrasts of the interference patterns at the two frequencies are known and a reference measurement is established, thereafter one can compute the gap or displacement from the amplitude ratio. Choosing one modulating frequency to be double the other one maximizes the variation in the amplitude ratio with change in the gap, thereby maximizing the measurement sensitivity.

This work was done by Grigory Adamovsky of **Lewis Research Center**. *For further information,* ***write in 140*** *on the Reader Request Card.*
LEW-14795

Wide-Field Retroreflectors

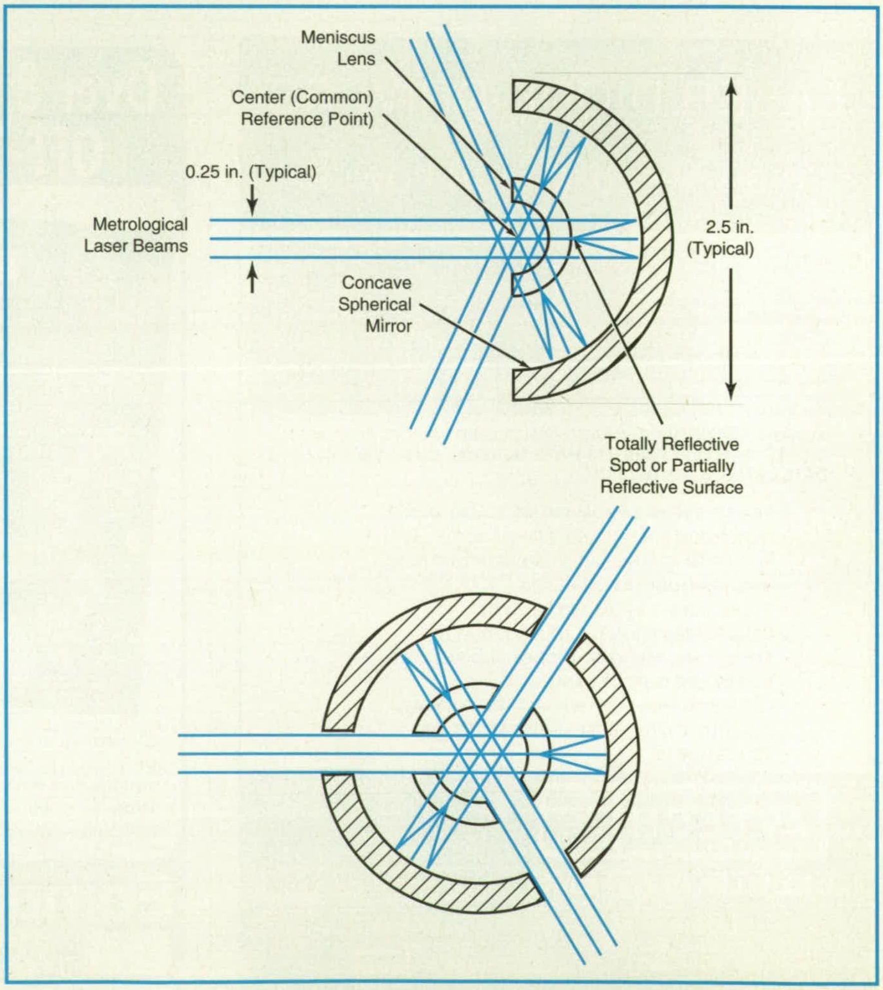
The angles between incident beams can be as large as desired.

NASA's Jet Propulsion Laboratory, Pasadena, California

Retroreflectors made of concentric spherical optical elements are being developed for use in interferometric metrological systems. A retroreflector of this type could be used, for example, to provide a reference point on a structure that is to be aligned precisely in two or three dimensions by use of intersecting laser beams. Its acceptance angle could be much larger than that of a cat's-eye or corner-cube retroreflector: it could simultaneously reflect laser beams separated by angles as large as 180°.

The principle of operation is most easily explained with reference to the configuration shown in the upper part of the figure. The retroreflector contains only two concentric hemispherical optical elements. The inner element is a meniscus lens, which acts as a corrector. The outer element is a concave spherical mirror.

Together, the two elements produce a highly corrected image on the radially outer surface of the meniscus lens. This surface is either coated all over to make it partially reflective or else made totally reflective at spots that contain the points to



The **Wide-Field Retroreflectors** are made of concentric optical elements. These two configurations are merely typical; other configurations could involve surfaces that are greater or lesser portions of spheres.

which the intersecting laser beams are expected to be focused. The partial or total reflection of each laser beam from this surface reverses the beam, thereby providing the retroreflector characteristic. The concentricity of the optical elements about the common reference point ensures identical performance at all angles. Furthermore, the spherical optical elements can be fabricated and assembled relatively easily.

The lower part of the figure shows a retroreflector in which three laser interferometer beams intersect at 120° intervals in a plane. Note that holes a little wider than the laser beams must be cut in the concave mirror and meniscus-lens elements. One could also construct a similar three-beam retroreflector for beams that do not all lie in the same plane.

This work was done by Norman A. Page and Eldred F. Tubbs of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 170*** *on the Reader Request Card.*
NPO-18630

Improved Optical Fiber Chemical Sensors

The active material would be placed in the core to increase sensitivity.

Langley Research Center, Hampton, Virginia

Calculations, based on the exact theory of an optical fiber, have shown how to increase the optical efficiency and, thereby, the sensitivity of an active-core, step-index-profile optical-fiber fluorosensor. These calculations are the result of efforts to improve the efficiency of an optical-fiber chemical sensor of a previous concept described in "Making Optical-Fiber Chemical Sensors More Sensitive" (LAR-14525), *NASA Tech Briefs*, Vol. 17, No. 3 (March 1993), page 77 as well.

In the previous concept, the active material is dispersed in a short length of cladding or placed in a thin layer along a short length of the interface between the core and the cladding. The cladding is permeable to the analyte (the substance to be detected), and the active material is one that either fluoresces or chemiluminesces selectively in the presence of the analyte. In the case of fluorescence, the cladding sources can be either excited by side illumination or by evanescent wave absorption, using an external source. In the case of chemiluminescence, no external source would be necessary because the analyte itself would interact with the cladding sources to produce light. Part of the excited radiation would travel down the fiber core and guided to a photodetector at the end of the fiber. The resulting output intensity indicates the concentration of the analyte.

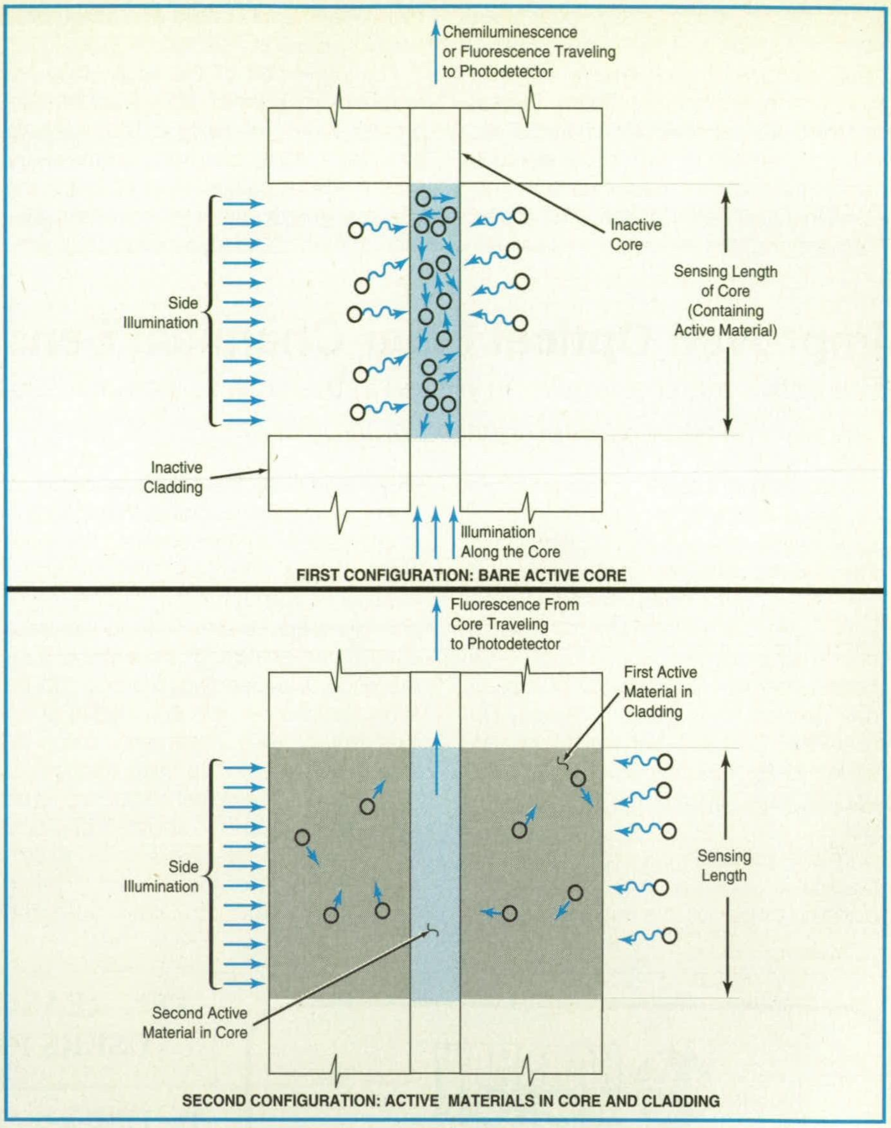
The figure shows two of several possible configurations for the core-fiber sensor: one with a bare sensing length of core fiber and the other with both core and cladding that are sensitive to the analyte. In the first configuration, the sensitive core would either chemiluminesce or would have its fluorescence modified by the presence of the analyte. In the second configuration, the radiation from the cladding sources would excite the sources in the core, the so-called two stage fluorescence. In both cases, the

fluorescence can be excited either by side illumination or core-light injection.

Numerical solutions have been obtained for the case of a step-index-profile fiber, in which the cladding is assumed to be infinitely thick. The fluorescent or chemiluminescent sources are taken to be uniformly distributed in the core. The results show that the intensity of the light that is trapped in the fiber core increases with the difference $n_{core}-n_{clad}$ and the factor ka, where k is the wavenumber of the light emitted by the sources and a is the core radius. It was also found that the efficiency of a core-source fiber is two orders of magnitude higher than the efficiency of a cladding-bulk distribution of sources.

This work was done by Claudio O. Egalon of Analytical Services & Materials, Inc., and Robert S. Rogowski of **Langley Research Center**. *For further information,* ***write in 145*** *on the Reader Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel; (804) 864-3521.



An **Optical Fiber Chemical Detector** of enhanced sensitivity could be made in several configurations, two of which are shown here. A portion of the fluorescence or chemiluminescence would be generated in the core, and thus would be launched directly into bound electromagnetic modes that would propagate along the core to the photodetector.

Master-Oscillator/Power-Amplifier Laser System

The output power can be modulated by direct modulation of the oscillator current.

Goddard Space Flight Center, Greenbelt, Maryland

Figure 1 illustrates a master-oscillator/power-amplifier (MOPA) laser system that can operate in a continuous-wave mode or in an amplitude-modulation (e.g., pulse) mode by modulation of the oscillator current. The power amplifier is a laser-diode-pumped neodymium:yttrium lithium fluoride (Nd:YLF) laser; the oscillator is a laser diode. Heretofore, amplitude modulation of the outputs of Nd-doped solid-state lasers was achieved by use of external lithium niobate waveguide electro-optical modulators, which have low

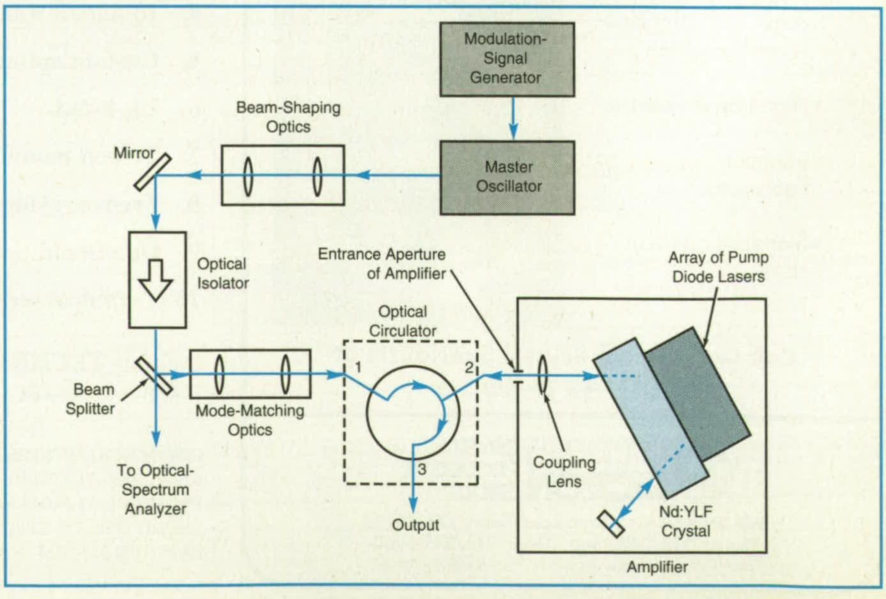


Figure 1. This **Master-Oscillator/Power-Amplifier** laser system offers relatively high efficiency and power. Because the drive current to the oscillator can be modulated, an external electro-optical modulator is not needed.

Optical Data Storage Using Spectral Hole-Burning Techniques

A system is designed to offer more data capacity for a fraction of the cost per megabyte.

SPARTA, Inc., Lexington, Massachusetts

Spectral hole-burning (SHB) materials have enabled development of an optical memory system that can store up to 10^{12} bits of information per cubic centimeter, a figure that theoretically could reach 10^{15} bits. In comparison, semiconductor random access memory chips and magnetic disks store about 10^{8} bits per cubic centimeter, and optical disks store about 10^{10} bits. Because the SHB memory system retrieves data with light beams rather than mechanical read/write heads, it should be an order of magnitude faster than magnetic disks.

According to projected cost estimates for SHB memory devices, the system would provide these capabilities for less than ten cents per megabyte of memory, a fraction of the cost of its competitors: RAM chips cost more than $10 per megabyte, and magnetic and optical disks cost about a dollar per megabyte.

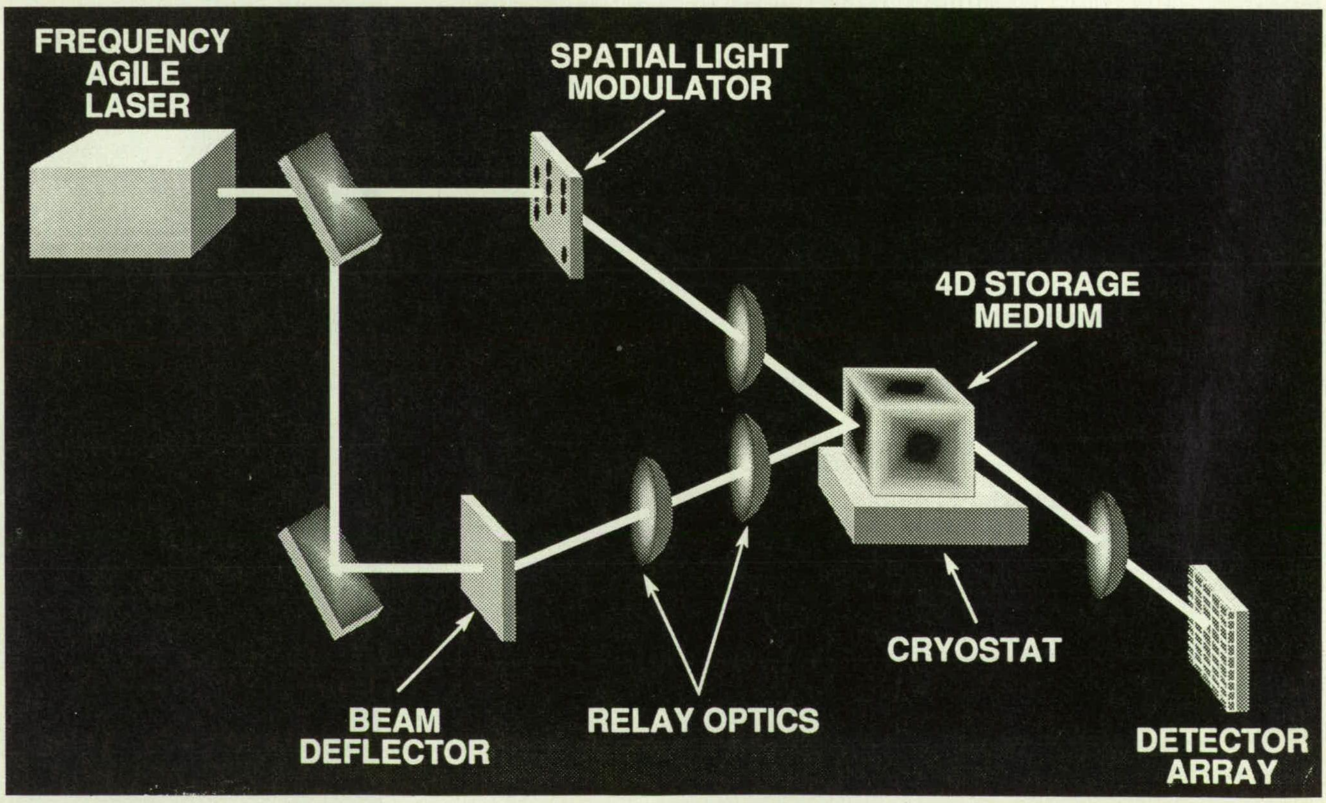
SHB media are materials that can record information through the process of photobleaching, in which a laser burns a transparent hole in the spectral response of a material to store data as a hologram. Photobleaching is extremely sensitive to changes in wavelength; each hole is transparent only to light of the wavelength that created it. As a result, the hologram can be recorded throughout the volume of a recording medium at many different wavelengths. This feature effectively adds a fourth dimension to the SHB media, allowing it to store thousands of holograms in a single medium.

In SPARTA's current designs, the SHB material must be cooled to 4 K to provide long-term data storage. Though these temperatures can be reliably obtained using commercially available cryocoolers, this requirement is a major impediment to eventual market acceptance. As a result, researchers are trying to identify SHB materials that do not require cryogenic cooling. They are also addressing several other technical issues, including ways to reduce the bit error rate and increase data rates.

Current designs include three types of devices that use SHB optical data storage technology:

(1) *Rapid access mass storage.* With their advantages in storage capacity per cubic centimeter, cost per megabyte, and access time, SHB storage systems could replace traditional memory devices. The larger the computer system, the more pronounced SHB's advantages. As a result, the first applications for rapid access mass storage are expected to be in supercomputers and file servers.

(2) *Content addressable memory.* A technique for searching and accessing data, content addressable memory is used in databases to search for matching data strings within 10 milliseconds, using parallel processors. Today's software-



Rapid Access Mass Data Storage System based on spectral hole-burning materials.

based search routines take seconds to perform similar matches.

(3) *Optical neural networks.* Neural networks incorporate the ability to learn and quickly process patterns by mimicking the structure of the brain. Because they can quickly reconfigure millions of interconnections, optical computers make ideal neural networks. Using holographic interconnects recorded in an SHB material, SPARTA has built a prototype optical neural network. This demonstration computer has a processing speed of more than 10 million interconnects per second and storage capacity of more than 1.8 million interconnects. The speed rivals the processing power of a fly's brain and is fast enough to perform simple pattern recognition problems. Later-generation computers, with as many as 10^{12} interconnections, would rival the processing power of a honeybee's brain and be fast enough to handle more sophisticated problems.

This work was done by Dr. Phillip S. Henshaw of **SPARTA, Inc.** *in a Ballistic Missile Defense Organization Small Business Innovation Research project, with additional support from the Air Force Office of Scientific Research. A fundamental patent on the use of multiple wavelengths in holographic architectures for optical computing and memory has been issued to SPARTA, and two others for specific device architectures have also been awarded. SPARTA will consider partnering arrangements to aid in commercializing the technology. Inquiries should be addressed to Dr. Henshaw at SPARTA, Inc., 24 Hartwell Ave., Lexington, MA 02173.*

Photopolymerized Electrolytes for Electrochromic Devices

Thin solid electrolytes are formed quickly and easily between electrode-bearing substrates.

Lyndon B. Johnson Space Center, Houston, Texas

Thin ion-conducting electrolyte films for use in electrochromic devices can now be fabricated relatively easily and quickly with any of a class of improved formulations that contain ultraviolet-polymerizable components. The formulations are liquids in their monomeric forms and self-supporting, transparent solids in their polymeric forms. Thus, a solid electrolyte film of this type can be formed in situ, as an integral part of an electrode/electrolyte/ electrode laminate, by placing a small amount of the monomeric liquid formulation between two transparent electrode-bearing substrates and exposing the laminate to ultraviolet light. The film thus polymerized acts not only as a solid electrolyte but also as a glue that holds the laminate together: this feature simplifies fabrication by reducing the need for sealants and for additional mechanical supports.

Each formulation includes at least the following four components: (1) a monomeric precursor to an ionizable polymer ("ionomer"), (2) a liquid, nonpolymerizing additive that complexes and solvates with the ionizable group and acts to improve the ionic conductivity of the final polymerized formulation, (3) a nonionic monomeric precursor that can enter into a copolymerization or cross-linking reaction with the ionizable monomer, and (4) an initiator of photopolymerization. A typical solid monomeric precursor is 2-acrylamido-2-methylpropane sulfonic acid and its Li^+ and Na^+ salts. Examples of complexing solvating additives include water, propylene carbonate, γ-butyrolactone, dimethyl formamide, N-methyl pyrrolidone, ethyl acetate, acetonitrile, ethanol, methanol, and ethylene glycol.

To render the desired gluelike function, one must minimize the amount of liquid, nonpolymerizing additive. Thus, one selects an additive that can complex directly with the ionizable group, forming a solvate with that group. When the additive is bound to the ionizable group, it does not form a separate liquid phase and therefore does not boil off at the normal boiling temperature of the additive; nor does it freeze at the normal freezing point of the additive. The solvate tends to form a cage around the ionizable group as well as a complex around the ion, thus separating the two charged species while shielding their charges from one another. Because of this separation and solvation, the charged counterion to the ionizable group (*e.g.*, H^+ or Li^+) can move more freely through the polymer matrix than it could in the absence of solvation. In addition, when the additive forms a solvate with the polymer, its plasticizing effect (lowering the viscosity of the polymer) is less than that of an additive that forms a liquid phase.

If the additive formed an extended fluid phase, it could solvate foreign ions. Insofar as corrosion products of electrochromic materials are ionic, excess additive exerts a destabilizing effect, reducing the lifetime of an electrochromic device. For example, excess water has been shown to reduce lifetimes of electrochromic displays that contain polysulfonic acid-type electrolytes. In general, the amount of conductivity-enhancing additive should not exceed the amount that can be accommodated in the solvation spheres of the ions of the polymer matrix. For example, maximum coordination numbers for solvates are about 8 solvent molecules per ionic group, although there is great variability depending on the local size and charge of the ion or ionic group.

The nonionic monomeric precursor must consist of a polar solvating moiety and an ethylenic linkage. It must have sufficient solvating power to dissolve the polar ionomeric precursor and the associated solvating additive. The most effective polar monomeric solvent precursors were found to be N,N′-dialkyl-substituted acrylamides and methacrylamides.

This work was done by Stuart Cogan and R. David Rauh of EIC Laboratories for **Johnson Space Center**. *For further information,* ***write in 186*** *on the Reader Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

David Rauh
Director of Research
EIC Laboratories, Inc.
111 Downey Street
Norwood, MA 02062

Refer to MSC-22040 volume and number of this Laser Tech Briefs *issue, and the page number.*

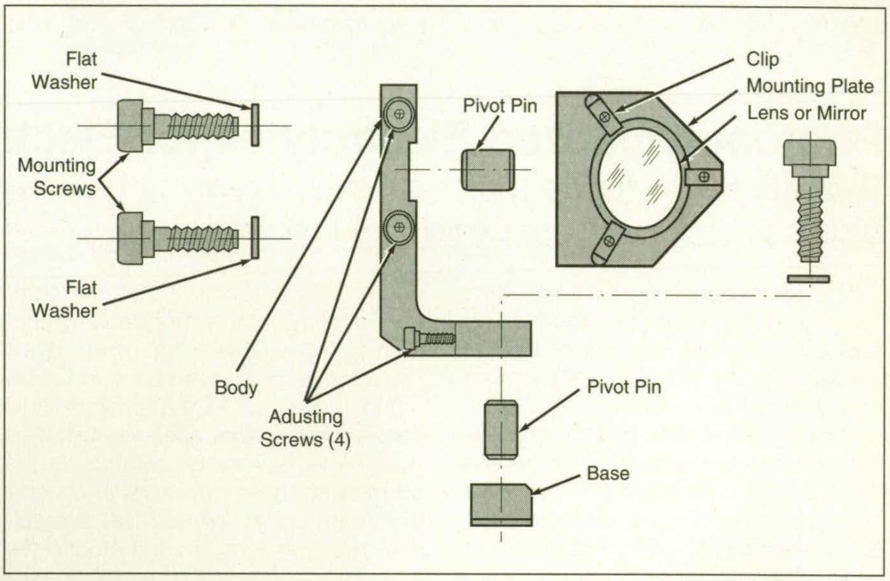
MECHANICS

Adjustable Optical Mount Is More Rigid

Vibrational and thermal distortions are reduced.

Langley Research Center, Hampton, Virginia

An improved mount for a lens or mirror in a laser offers rigidity similar to that of a nonadjustable optical mount. Thus, in comparison with older adjustable optical mounts, this one is less susceptible to movements and distortions caused by vibrations and by thermal expansions and contractions. Unlike older adjustable mounts, this mount contains neither adjustment rods (which grow or shrink as the temperature varies) nor springs (which transmit vibrations to the mounted optic). Thermally induced deviations of this mount have been measured to be only about one-fifth those of commercial mounts tested in the same temperature range. All parts are over-aged in a heat-treating process. Then, a coat of Teflon Penetrate Hardcoat Anodize (or equivalent) is applied to obtain a coefficient of friction of 0.16 to produce smooth adjustable capabilities.



This **Adjustable Optical Mount** is less susceptible to vibrational and thermal distortions than are older adjustable optical mounts.

The improved adjustable mount includes three frames denoted as the base, the body, and the mounting plate (see figure). Screws and pivot pins join the mounting plate to the body and the body to the base. Screws fasten the base to the mounting surface. The mirror or lens is held in the mounting plate by clips and screws. Four screws are used to adjust the position of the mirror or lens by turning the mounting plate on the mounting-plate/body pivot pin and the body on the body/base pivot pin. When the adjustments are complete, the adjusting screws are loosened or removed.

This work was done by Bill G. Asbury of Lockheed Engineering & Sciences Co. and David S. Coombs, Irby W. Jones, and Alvah S. Moore, Jr., of **Langley Research Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center; (804) 864-3521. Refer to LAR-15060.

FABRICATION TECHNOLOGY

Connector for Embedded Optical Fiber

There is no need to align a coupling prism and lenses.

Marshall Space Flight Center, Alabama

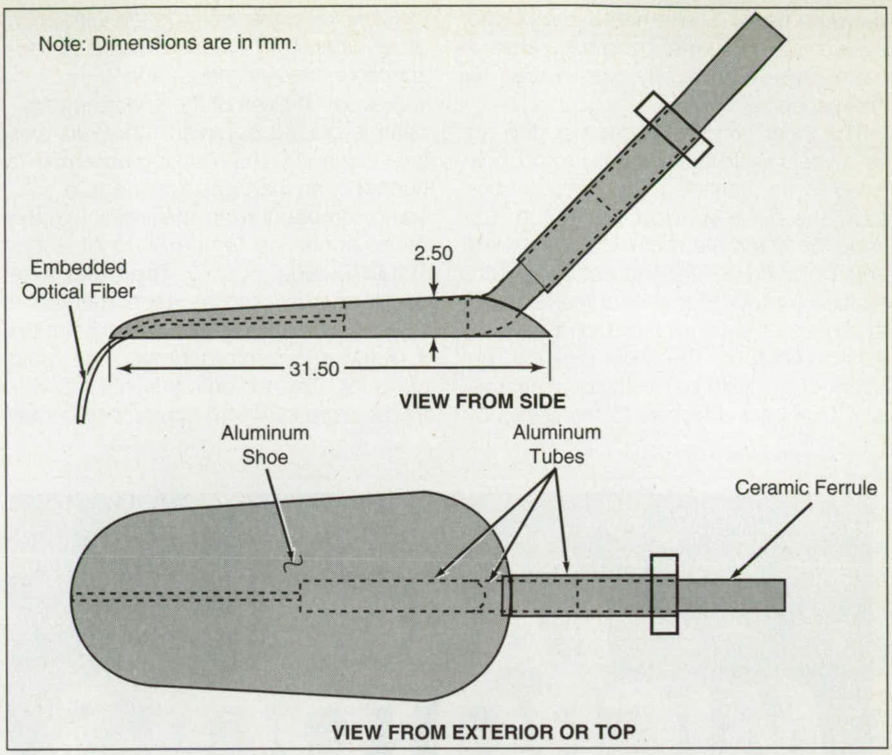
The figure illustrates a partly embedded fixture for coupling light between an external optical fiber and an optical fiber embedded in a structure made of composite material. Heretofore, connections to embedded optical fibers have been made by use of fiber pigtails protruding from the structures and, alternatively, via embedded connectors that contained lenses and right-angle prisms. These techniques entail disadvantages that include breakage of fibers and the need to maintain the prisms and lenses in precise alignment relative to each other and to the optical fibers throughout manufacturing processes. In comparison with these techniques, the partly embedded fixture provides the advantages of a sturdier connection without need for additional optical components and without alignment problems.

The fixture includes a base, a tube bent at a 45° angle, and a ceramic ferrule. The embedded optical fiber passes across the inner surface of the base into the 45° tube and is terminated and polished at the surface of the ferrule. The

base can be made to conform to the surface of the structure in the vicinity of the outlet for the embedded optical fiber. The entire fixture is embedded in the composite material of the structure, such that the ferrule protrudes fully to provide an interface connection to an external fiber.

This work was done by Charles Wilkerson, Steven Hiles, J. Richard Houghton, and Brent W. Holland of **Marshall Space Flight Center**. *No further documentation is available.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center; (205) 544-0021. Refer to MFS-26246.



A **Partly Embedded Fixture** is simpler and sturdier than are other types of outlets for optical fibers embedded in solid structures.

Making Three-Dimensional Windows for Laser Anemometry

Design objectives include nonperturbation of flow, adequate strength, and minimal optical error.

Lewis Research Center, Cleveland, Ohio

Windows that have compound (three-dimensional) curvatures are being designed and fabricated for installation on research turbines and compressors to enable the use of intersecting laser beams to measure the flows in these machines. The inner surfaces of these windows are required to conform to the flow-surface profiles of the machines, so as not to perturb the flows. The designs of the windows are also subject to the competing requirements for adequate strength (which increases with thickness) and minimization of thickness to minimize refractive optical errors: an acceptable compromise

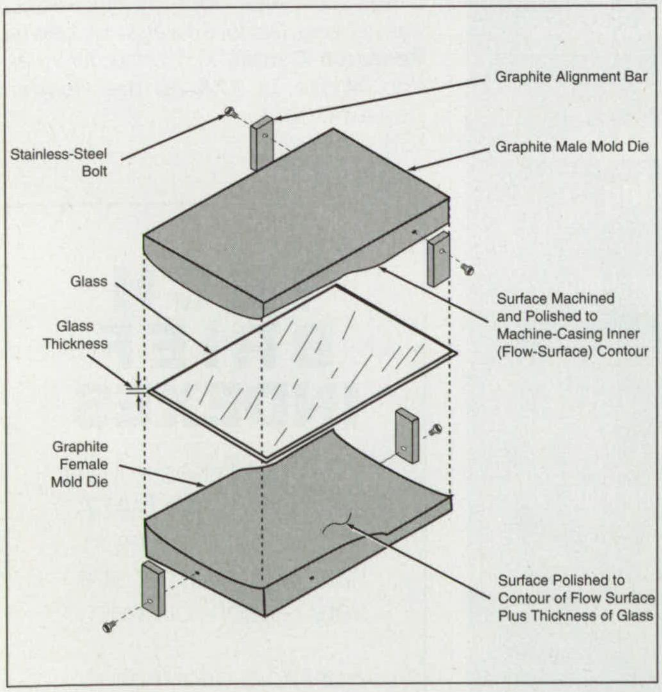


Figure 1. The **Sheet of Glass Is Formed** into a window by heating it in the mold to slump it to the desired contours

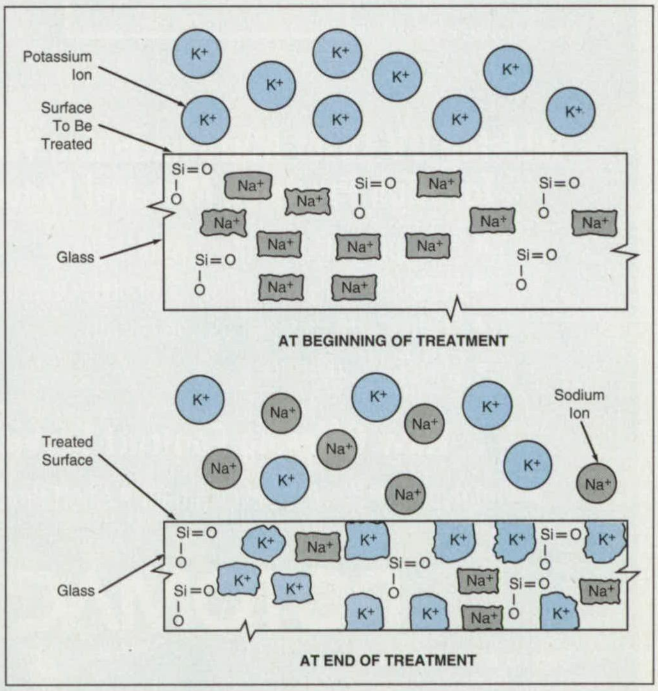


Figure 2. The **Window Is Strengthened** by an ion-exchange process. Potassium ions crowd out sodium ions in a surface layer, placing that layer under compressive stress.

between these requirements is achieved by use of a sodium-alumino-silicate glass that can be chemically prestressed to strengthen it.

The inner window surface is defined by a male mold die machined and polished to the specified flow-surface contour; the outer window surface is defined by a female mold die machined and polished to the theoretical outer-surface contour of a layer of the required thickness of glass overlaid on the flow-surface contour. The mold dies can be made of graphite or machinable ceramic. Guide bars attached to the edges of the dies keep the dies aligned with each other when they are assembled as described in the next paragraph.

A sheet of glass of the specified thickness is placed between the mold dies (see Figure 1). The resulting assembly is heated in an inert-gas furnace to a softening temperature in the vicinity of the mean annealing temperature of about 1,100°F (about 600°C). The exact temperature is chosen by experimentation to soften the glass just enough to make it slump into conformity with the mold surfaces. The assembly is held at this temperature for 4 to 6 hours, then cooled to ambient temperature. The ultimate quality of the window depends on the scrupulous maintenance of cleanliness of the glass, mold, and furnace at all stages of this process.

It may be necessary to repeat the slumping process several times, possibly with variations in temperature, inversion of the mold, and variations in the weights until the glass conforms entirely to the required inner and outer surface contours and exhibits the required surface quality. Once the surfaces are as required, the window is annealed to relieve residual stresses. The edge of the annealed window is trimmed to the required dimensions by use of a numerically controlled water-jet cutting machine, then the edge is rounded by use of sanding belts coated with aluminum oxide or diamond particles.

Next, the window is immersed in a bath of molten potassium nitrate: this is the strengthening chemical treatment, and it involves exchange between the potassium ions of the bath and the sodium ions in the glass as manufactured (see Figure 2). The larger potassium ions crowd sodium ions out of a thin surface layer, the net result being a surface layer about 0.010 in. (0.25 mm) thick that is compressively prestressed. Thereafter, the window can fail only when an applied tensile load exceeds the compressive prestress or when an impinging object penetrates the surface compression layer. The chemically strengthened window is glued into a frame, which is tested for mechanical strength and then mounted on the experimental machine.

This work was done by Vincent G. Verhoff and David Kowalski of **Lewis Research Center**. *For further information,* ***write in 178*** *on the Reader Request Card.*
LEW-15745

Books and Reports

More About Graded-Reflectance Optics for Coherent Lidar

A super-Gaussian reflectance profile may optimize performance.

A report presents a theoretical study of the energy-extraction and power-transmission efficiency of an unstable-resonator laser cavity, the output mirror of which has a graded reflectance. The general reflectance profile considered in this study is a super-Gaussian; namely

$$R(r) = R_o \exp[-2(r/w_m)^n]$$

where R_o is the reflectance at the optical axis, r is the radial coordinate (distance from the optical axis), and w_m is that radius at which the reflectance is R_o/e^2. The parameter n is called the "order" of the super-Gaussian; it has a lower bound of 2, which corresponds to a conventional Gaussian profile. The study is directed toward maximizing the efficiency of a coherent lidar system in which the laser and its output-coupling optics constitute the transmitter.

A similar study was reported in "Comparative Study of Resonator Optics for Lidar Applications" (NPO-17776), *NASA Tech Briefs* Vol. 16, No. 6 (June 1992), page 58. In that study the performance of a system with a Gaussian reflectance profile is compared with that of a hard-edge reflectance profile. In both studies, the figure of merit used to quantify the performance of a system is an overall power-transmission efficiency that combines the energy-extraction efficiency of the laser resonator with the effect of far-field brightness of the laser beam as expressed in terms of a resonator antenna efficiency.

As in the previous study, the analysis in this study follows the backward-propagated-local-oscillator (BPLO) approach, in which the local-oscillator laser beam in the receiver is imagined as being projected through the receiver optics to the target, where it is convolved coherently with the far-field laser beam. The far-field distributions of the BPLO and transmitted beams are computed from diffraction integrals, using, respectively, a conventional Gaussian distribution of BPLO irradiance and a compound super-Gaussian (arising from the convolution of the super-Gaussian internal laser mode with the super-Gaussian reflectance profile), both truncated at the edge of the transceiver pupil.

Parametric studies were conducted by computing the overall power-transmission efficiencies of systems with selected values of n and selected values of the laser-cavity magnification. In these calculations, the truncation parameter of the transceiver pupil (a/w_L, where a is the radius of the pupil and w_L is the radius at which the intensity of the local-oscillator beam is $1/e^2$ times that at the optical axis) is selected to equal 0.84 — the value determined in previous studies to be optimum for both Gaussian and compound-Gaussian profiles. The numerical results of the calculations have been interpreted as showing that by choosing $6 \leq n \leq 10$, one can obtain an optimal tradeoff between the advantages of graded reflectance (namely, high quality of the output beam and its propagation) and the onset of diffraction. Furthermore, the results seem to show that output laser-beam modes with inferior propagation characteristics are produced when $R_o > 0.6$.

This work was done by David M. Tratt of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Optimizing Coherent Lidar Performance with Graded Reflectance Laser Resonator,"* ***write in 175*** *on the Reader Request Card.*
NPO-18677.

Optoelectronic Terminal-Attractor-Based Associative Memory

Spurious states are reduced by exploiting terminal attractors.

A report presents a theoretical and experimental study of an optically and electronically addressable optical implementation of an artificial neural network that performs associative recall. As used here, "associative recall" means that when prompted with a complete or partial input image, the neural network responds by retrieving whichever one of several complete previously stored images that the input image most nearly resembles according to some quantitative criterion of resemblance. The images that are of primary concern in this study are binary (black and white) images in one and two dimensions ($n \times 1$ and $n \times n$ picture elements, where n is an integer ≥ 1).

The study approaches the problem from the perspective of exploiting the properties of terminal attractors in the phase space of the neural dynamic system to reduce the number of spurious states that occur in a Hopfield-model neural network. The most common spurious states are stable states that were not stored originally. Others are stored states that are more distant from the input state (resemble the input image less than another sorted image does). Still others are oscillating states. By reducing the number of spurious states, one can increase the number of valid states that can be stored.

Terminal attractors represent singular solutions of the equations of the neural dynamic system and can be characterized by finite relaxation times, no spurious states, and infinite stability. Spurious states are false attractors trapped in local minimums of the energy landscape of the phase space. Terminal attractors can serve as means for real-time, high-density associative memories and for solution of neural-network-learning and global-optimization problems.

The differential equations of neural dynamics in the original terminal-attractor model are based partly on the assumption that neural states are continuously variable and that the input/output behaviors of neurons are characterized by sigmoidal thresholding functions. These assumptions present difficulties for optical implementation. Accordingly, the main text of the report begins with a theoretical discussion of the terminal-attractor model. The original model, with its continuous differential equations, is transformed into a discrete model, with proof of stability of the solutions.

The report then presents examples of optical implementations of the discrete model of the terminal-attractor-based associative memory.

The report shows by computer simulation that a terminal-attractor-based associative memory can have a perfect convergence in associative retrieval and an increased storage capacity. Engineering problems that arise in optical implementation are discussed, citing relevant experience with the inner-product experimental apparatus.

This work was done by Hua-Kuang Liu and Jacob Barhen of Caltech and Nabil H. Farhat of the University of Penn-

sylvania for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Optical Implementation of Terminal Attractor Based Associative Memory,"* ***write in 149*** *on the Reader Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office–JPL; (818) 354-5179.

Refer to NPO-18790.

Laser Metrology System for a Segmented Telescope Reflector

This system would be used in pointing as well as in maintaining the surface figure.

A report describes a proposed laser metrology system in a far-infrared telescope with a segmented primary reflector. The telescope is to be flown in outer space and used to observe celestial objects. The laser metrology system would be mounted on a structure that supported a secondary telescope reflector and would measure the relative positions and alignments of the segments of the primary reflector. These measurements would be used by a figure-maintenance control system to adjust each segment (by use of motor-driven lead screws) to compensate for thermal and other distortions of the segmented primary-reflector surface. These measurements would also be used to establish the relationship between the pointing (aiming) direction determined by an external figure-guidance system and the boresight of the telescope as defined by the primary reflector, secondary reflector, and focal-plane assembly.

The laser metrology system would include fiber-optic-coupled heterodyne laser interferometers, which would measure the relative displacements of the primary-reflector segments with respect to the secondary-mirror-supporting structure. The optical heads of the interferometer would be configured in a hexagonal pattern on the secondary reflector with three heads per primary-reflector segment. Three corner-cube retroreflectors would be located on edges of each segment. Each optical head would provide several beams from a common laser source through a multiple-prism manifold, such that two beams would strike each corner-cube retroreflector. The ensemble of beams would resemble a truss structure and thus would be called an "optical truss."

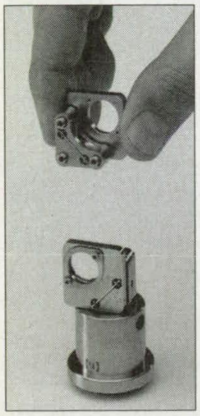
The beams returned to each optical head would interfere in the same beam splitter and would be imaged separately on individual optical fibers, which would deliver the light to remote detectors. The outputs of the detectors would be processed to obtain the desired geometric quantities. Computer simulations of expected performance show that the laser metrology system would enable the figure-maintenance control system to reduce those wavefront errors attributable to segment errors to as little as 0.2 μm, and that pointing errors would be no greater than 0.16 arc second.

This work was done by Kenneth H. Lau of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "A Dual Purpose Optical Truss Laser Metrology System for a Space-Based Far-IR Segmented Telescope: Figure Maintenance and Pointing Control,"* ***write in 153*** *on the Reader Request Card.*

NPO-18850

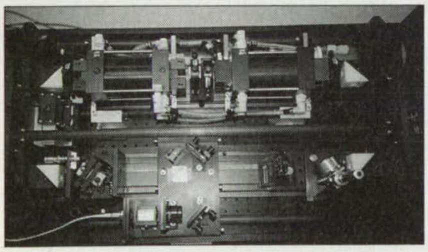
NEW PRODUCT SHOWCASE

A series of **micropositioners for vacuum applications** is available from New Focus, Sunnyvale, CA. The line includes corner mounts for ½" optics, pedestal bases, and 6-80 screw and nut sets. Made of a special aluminum bronze alloy and stainless steel, the micropositioners are said to be vacuum- compatible down to 10^{-9} torr. New Focus plans expansion of the line throughout the year.



For More Information Write In 781

Light Age, Somerset, NJ, has developed an all-solid-state **tunable pulsed ring laser** that it says can deliver single-longitudinal-mode pulses throughout the UV-VIS-IR spectrum. The diode-injection-seeded alexandrite PAL™ ring laser produces 20-100-MHz linewidths and relatively long Q-switched pulse durations (50-100ns). Designed for atmospheric lidar, the laser is also suited to high-resolution spectroscopy, holography, photolithography, and pumping of ultranarrow-band visible and IR optical parametric oscillators and of other laser sources, according to Light Age.



For More Information Write In 783

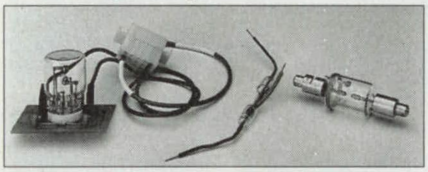
VISIFLOW is a PC-based software package from Oxford Lasers, Acton, MA, that uses **particle image velocimetry** (PIV) to extract velocity information from images of fluid flows. A laser strobe provides multiple exposures of particle images in a selected plane of a flow field. One of a number of techniques measures displacement between the images and division by time yields velocity. VISIFLOW can be used with data from photographic prints, film, video, or high-resolution video, and has applications in engine and combustion analysis, wind tunnel flows, spray analysis, flow visualization, and more.

For More Information Write In 784

Helios, Longmont, CO, has developed a new line of hydrogen fluoride/deuterium fluoride (HF/DF) **mid-IR lasers** that produce up to 10 W of continuous-wave power in the wavelength ranges of 2.6-3.0 microns and 3.6-4.0 microns. Helios says it has optimized its MiniLaser design, offering improved vacuum systems, new gas supply options, and simplified exhaust gas treatment. Three models, the LP, S, and E, generate HF multiline powers of 0.5 W, 5.0 W and 10.0 W. Helios' air-breathing mode of operation reduces gas cylinder changes by 55%, the company says.

For More Information Write In 787

Oriel, Stratford, CT, says its new **pulsed xenon flashlamp systems** are an ideal choice when sample heating, bleaching, and long-lived triplet states with forbidden ground transitions create problems. Three of the four new models, the capillary, guided arc, and large bulb types, have pulses of microsecond duration, energy levels from 0.16-5 J and repetition rates from 60-100 Hz; the fourth, a coaxial lamp, provides repetition rates from 0-100 Hz. The first three lamps can be fitted to Oriel's Q housing.



For More Information Write In 782

Tropel, Fairport, NY, announces a new **precision refractometry service** that it says provides the world's most advanced measurements of index of refraction. The company notes that optical materials manufacturers and system designers can get measurements accurate to six significant digits for wavelengths from 200-800 nm. In addition, Tropel offers precision dispersion measurements and indexes at specific laser lines.

For More Information Write In 780

From Instruments S.A., Edison, NJ, come the SPEX 270M (0.27m) and Jobin Yvon HR460 (0.46m) **imaging spectrographs**, which the company says have the highest resolution levels and imaging performance of any spectrometers in their class. The units offer SPECTRUM ONE CCD detectors for high sensitivity and the new SPECTRAMAX spectroscopic software for what the manufacturer calls seamless control of every aspect of the spectrometric and detection systems.

For More Information Write In 785

Hamamatsu, Bridgewater, NJ, is offering the H5773 and H5783 **light sensor modules** that incorporate the new compact OPTO-8 photomultiplier tube and operating power supply with low voltage operation (+11.5-+15 V) and low current draw (12mA). Radiant sensitivity at 25°C is $8X10^{-3}$ and anode pulse rise time is 0.65 ns. The H5773 series, directly mountable on a circuit board, and the H5783 cable output series are both available with spectral response ranges of 300-650 nm, 300-820 nm, and 185-650 nm.

For More Information Write In 786

From Rycom Instruments, Raytown, MO, comes the new 5555 **optical power meter**, a palm-sized meter the company describes as combining a state-of-the-art signal processor with simple operation. With just three controls (on/off, dBm/dB, wavelength), the unit uses an InGaAs detector and operates on calibrated wavelengths of 850 nm, 1300 nm, and 1550 nm. Resolution is 0.01 dB.

For More Information Write In 788

Xenon, Woburn, MA, announces the development of a **sapphire flashlamp** that improves upon the lifetime of quartz and silica lamps. With a higher melting point and more efficient heat transfer, sapphire also avoids darkening degradation. It also is said by the company to offer a wide transmission range.

For More Information Write In 794

Litton Poly-Scientific, Blacksburg, VA, has a **fiber optic rotary joint** that couples optical signals through a rotating interface. The FO4698, a passive device that contributes no noise to a system and consumes no electricity, is bidirectional and operates in temperatures from -55 °C to +60. Fiber sizes available include 50/125, 100/140 and 200/240. Rotation rate is 100rpm. The units are designed for easy hookup to 906, SMA, or ST style cable assemblies.

For More Information Write In 789

The Micron/Viewer 7290 **infrared viewing system** from Electrophysics, Fairfield, NJ, has a wide spectral response, extending from the visible (400 nm) through the near-IR to more than 2 microns. It can be used for viewing, aligning and profiling near- and far-field intensity distributions of infrared laser beams, for the subsurface inspection of materials transparent to radiation beyond 1 micron, and for imaging 1.3 and 1.55-micron laser diode sources.

For More Information Write In 791

Laser Technology, Germantown, PA, offers advanced **laser shearography equipment** that the company says can do in seconds what ultrasound needs minutes for. The equipment inspects up to 36" X 48" at a time with full-field video presentation in color or black-and-white. Noncontact and noncontaminating, shearography is not affected by part contours or shape. Results can be recorded on disk or videotape.

For More Information Write In 792

The new SLS **pulsed Nd:YAG laser system** from Lasag, Arlington Hts., IL, is designed for fine spot and seam welding applications with spot diameters ranging from 60-600 microns. Standard models with 10W or 20W of average laser power are available. Options are a TV camera and monitor, RS-232 interface, and built-in HeNe aiming laser.

For More Information Write In 793

Dynamic Control Systems, Delta, BC, Canada, has added the Dynavision SPR-02C to its line of intelligent single-point long-range **profiling sensors**. Accuracy is 0.025mm over the 15-40cm range. The sensor uses a proprietary non-laser light source, and its all-digital technology eliminates errors due to changes in temperature or scan rate. Output is digital or analog, field-adjustable scan rate is up to 750 Hz, and as many as 255 sensors can be connected on a multidrop serial line.

For More Information Write In 795

New from Environmental Optical Sensors, Boulder, CO, is the 2001MSC, which the company calls the first narrow-linewidth **tunable laser system** for less than $10,000. An innovative modular design makes changing wavelength regime a matter of removing and inserting different modules. Output is switchable between a single-mode fiber and a collimated free-space beam. The linewidth of less than 100 kHz, absolute wavelength/wavenumber readout to 0.02 nm and easy modulation or locking on an external wavelength reference to 1 kHz address spectroscopic applications from atomic physics through biomedical imaging.

For More Information Write In 796

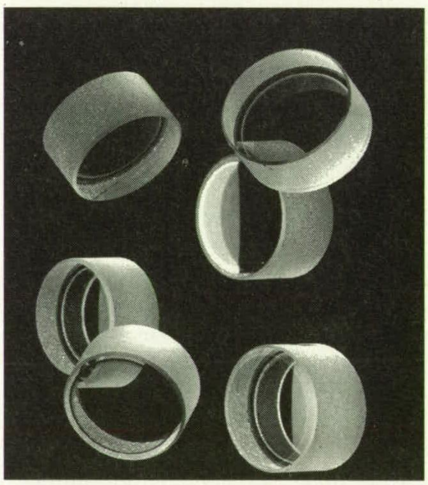
Watlow Infrared, Decorah, IA, offers its IR Junior, a noncontact **infrared sensor** with a temperature sensing range of 32-1000 °F (0-538 °C). It can withstand ambient temperatures of 32-175 °F (0-80 °C). The unit is NEMA 4X water- and corrosion-resistant, permitting it to be given a wash-down cleaning. It can be ordered with a right-angle mirror for tight spaces. An 18-28 V DC power connection is all that is required for operation.

For More Information Write In 799

Santec Photonics Laboratories, Holmdel, NJ, announces the OTF-100 electronically controlled **optical wavelength selector** with a high tuning speed (≥10 msec), utilizing the company's polarization-independent interference filter. It is designed for erbium-doped fiber amplifier applications, precise wavelength selection in high-density wavelength division multiplexing, coherent communications and CATV. Polarization-dependent loss is very low (>0.1 dB P-P). A rack-in version is available.

For More Information Write In 813

Available from Amoco Laser Co. Optics Group, Naperville, IL, are standard **laser output couplers** in a variety of radii and reflectances. The ALC couplers are 7.75 mm in diameter and 4 mm in thickness. State-of-the-art polishing techniques assure low-scatter surfaces. The group also offers quality thin-film coatings on both sides of the optics.

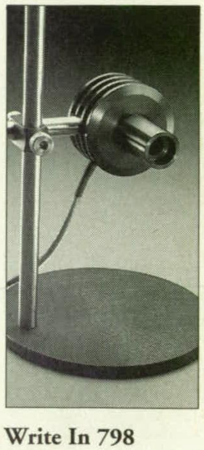


For More Information Write In 797

A new **optical analysis module** from Rheometrics, Piscataway, NJ, to be used with the company's Dynamic Stress Rheometer (SR-200, SR-500), enables nondestructive measurement of dichroism and birefringence while simultaneously measuring creep, recovery, and dynamic mechanical behavior of materials capable of transmitting light, such as polymer blends, block copolymers, suspensions, dispersions, and other complex materials. Data rates are up to one point every 5.7 msec, and frequency range is 1 X 10^{-5} to 500 radians/sec.

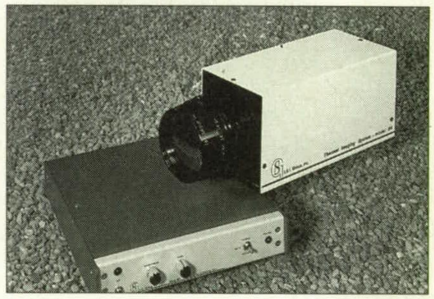
For More Information Write In 800

Molectron Detector, Portland, OR, announces the new high-sensitivity **thermal laser probe**, Model PM3, for use with solid-state diode lasers and diode-pumped Nd:YAG lasers. It offers broad, flat spectral response, 10 -μW resolution, and response time of a few seconds. Detection range is 50 μW to 3 W and wavelength response range 0.19-11 μm. The company says the PM3's advanced sensor technology offers linearity at high peak power levels, no photocurrent saturation, and no need for wavelength correction.



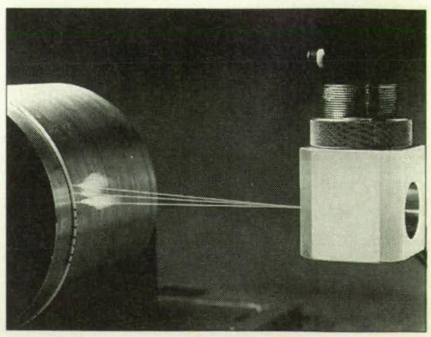
For More Information Write In 798

ISI Group, Albuquerque, NM, makes available the VideoTherm 86, a pyroelectric-vidicon-based **infrared camera** that delivers a standard television output. It features a remote camera control unit with controls for brightness, gain, and poling, and has several lenses to choose from. It can be configured to image in the 8-14-μm or the 0.6-25-μm spectral regions.



For More Information Write In 805

The Industrial Laser Source, Hopedale, MA, introduces a noncontact **microdrilling system** for nonmetallic substrates. The Laser Microdrilling System can selectively drill holes down to 0.005" or slots up to 0.120", operating in-line with most flat or tubular nonmetallic extrusion processes. User-selectable hole placement is accurate to better than +/- 0.005". Operating line speeds are up to 300 in./sec. The system is priced from $38,000 depending upon interface requirements.



For More Information Write In 801

From Honeywell's Micro Switch Division, Freeport, IL, comes the HOA1406 series of **reflective sensors**. Just 0.100" thick, the HOA1406 is an arrowhead-shaped sensor containing an IR-emitting diode (IRED) and detector. The hermetically sealed metal components are mounted side by side on converging optical axes. The sensor offers either a phototransistor or photodarlington output. Volume pricing is $6-7 each.

For More Information Write In 802

Specifically designed for disk mastering, the MicroSpot™ UV **micro-objective** from Tropel, Fairport, NY, is a lens of 0.90 NA with what the company calls flawless performance from 351-680 nm. It offers 0.25-μm spot imaging, high transmission and low reflection, large field of view, and low mass housing.

For More Information Write In 808

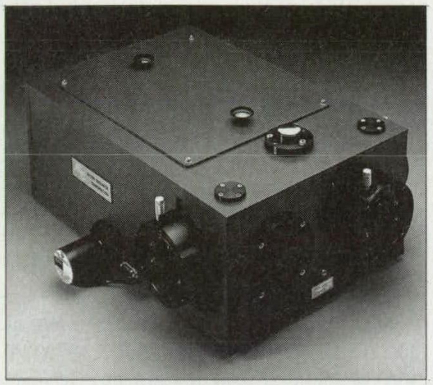
The new LAI 701 RA **regenerative amplifier** from Light Age Inc., Somerset, NJ, is designed for use with picosecond or chirped-pulse femtosecond lasers in the 720-800-nm spectral range. Based on the same technology as the company's 101 PAL pulsed alexandrite laser, the unit is suitable for amplifying the output of commercially available ultrafast Ti:sapphire and dye lasers. Repetition rate is greater than 100 Hz. Directly flashlamp-pumped, the amplifier is capable of terawatt power densities after pulse compression using compatible single-pass amplifier stages.

For More Information Write In 803

CeramOptec, Enfield, CT, says it is the first to offer **fused silica** capillary tubing and optical fiber capable of continuous use up to 405 °C. Because this exceeds the continuous-use temperature of aluminum coatings, the company says, the need for long-lead-time high-cost metal coatings is eliminated. The high temperature capability allows for better analysis of petroleum products and for demanding optical fiber applications.

For More Information Write In 807

Acton Research Corp., Acton, MA, has designed its new Model 505F **monochromator/spectrograph** for maximum light-gathering power. The company says the 0.50-m focal length and large 110-mm X 110-mm gratings result in a fast f/4 optical system. The 505F's multiport optical system can accommodate many accessories. RS-232 computer compatibility is built in, and IEEE-488 is optional. The remote scan controller has menu-driven pushbutton operation. Gratings are a self-aligning snap-in design for easy interchangability.



For More Information Write In 809

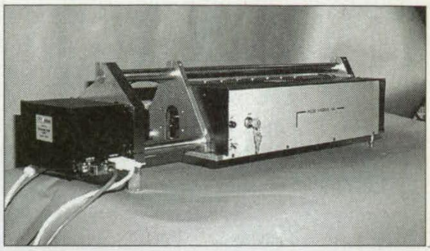
Newport Corp., Irvine, CA, has introduced the Model 2835 **dual-channel optical meter**. Based on the company's Model1835 single-channel unit, the new one has the same DC power range (100 fW to 1 kW), compatibility with Newport's NIST-traceable semiconductor, thermopile, and pyroelectric detectors, and a spectral range with these of 250-20,000 nm. Pulse enegies of 10 fJ to 20 J can be measured at repetition rates from single-shot to 2 kHz. DC, peak-to-peak, pulse, and dosage measurements can be read directly in watts, dBm, dB, joules, ergs, amperes, and volts.

For More Information Write In No. 814

Molectron Detector, Portland, OR, introduces a self-contained battery-operated **laser power meter** designed for medical and dental fiber laser systems. The Model PM600 integrates a thermal laser sensor in a rugged package that includes low-noise solid-state electronics and a 3½-digit LCD. The unit can measure pulsed or CW output over a power range of 0.10-10.0 W and a broad spectral range from 0.35-11.0 μm, taking in UIS to far-IR lasers.

For More Information Write In 810

The LP-30 pulsed **carbon dioxide laser** from Pulse Systems Inc., Los Alamos, NM, is now integrated with a Three-Sigma Agile Tuner that accommodates up to five wavelengths in repeating patterns. The company says the "agile-tuned" laser provides fast and accurate tuning.



For More Information Write In 811

Litton Poly-Scientific, Blacksburg, VA, offers a new multiple-format **fiber optic digital transceiver**. The EO3691 multilink digital data transceiver has RS-232, RS-422, and TTL data formats that can be reconfigured by simply changing the input and output selections on the terminal strip. It is also capable of protocol conversion (i.e., RS-232 in, RS-422 out, etc.). Single or bidirectional signals can be transmitted in all formats. Data rate in RS-422 and TTL is DC-100 kB/sec, and for RS-232 DC-20 kB/sec. A high-data-rate version capable of DC-1 MB/sec is also available.

For More Information Write In 815

Applied Photonics Inc., Hauppauge, NY, is offering the Model RP-30 refrigerated **cryogenic purifier** for industrial excimer lasers. Because it does not require liquid nitrogen, the RP-30 lowers operating costs by not consuming LN2, by reducing downtime, and by lowering laser gas consumption, the company says. With pushbutton local control and remote control for long-term unattended operation, the RP-30 complies with applicable TUV and IBM safety and electrical standards.

For More Information Write In 806

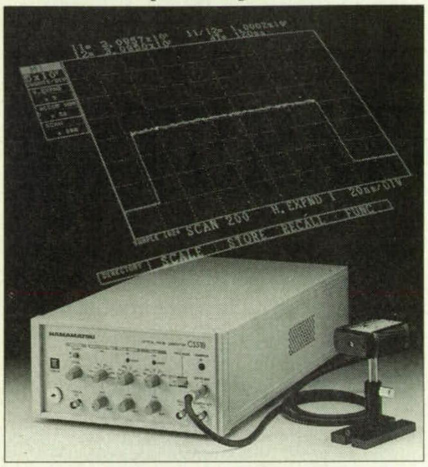
Teledyne Brown Engineering, Huntsville, AL, has a selection of low-cost off-the-shelf diffractive optical **fanout gratings** for most common laser wavelengths, including linear patterns of 3-31 equally intensive spots, crosses of 5,9, and 17 spots, circles of either 8 or 16 spots, and a 16-spot box. Users can also specify custom requirements for unique devices.

For More Information Write In 804

The Model DIP-150 from Polytec PI Inc., Costa Mesa, CA, is a new **thickness-gauging laser/sensor system** that measures optically opaque materials to tight tolerances at high speeds of 50 m/sec.The unit uses an eyesafe pulsed diode laser, fiber optics, and computer-interfaced digital electronics. The DIP-150 can be utilized in explosion-prone, high-radiation and other difficult environmental settings.

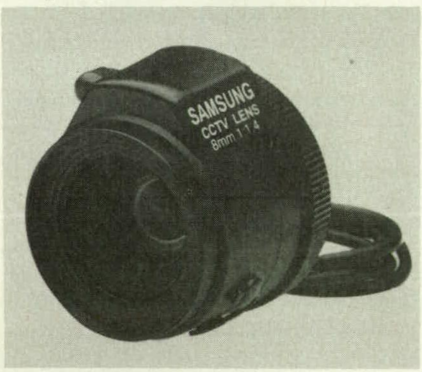
For More Information Write In No. 812

A new member of its family of **optical square-wave generators**, the PLP-05 from Hamamatsu Photonic Systems, Bridgewater, NJ, consists of a controller with a maximum repetition frequency of 10 MHz and delay from 10 nsec to 1 msec and one of nine laser diode heads that cover the wavelength range from 650-1550 nm. Amplitude flatness is 5 percent, rise time 200 psec, and fall time 300 psec. Window, FC-type, and graded-index 50/125 optical outputs are available.



For More Information Write In No. 816

Samsung Optical America, Secaucus, NJ, announces three new C-mount **auto-iris lenses** for CCD cameras, to be used with 1/2" or 1/3" cameras. Model SLA 064C is a 6-mm lens, SLA 084C an 8-mm lens, and SLA 124C a 12-mm lens. With a 1:1.4 maximum aperture ratio, these lenses offer excellent performance in low-light conditions, the company says.



For More Information Write In No. 819

ROHM Corp., Antioch, TN, says its new series of solid-state **LEDs** has exceptionally high luminosity and long component life that makes it very cost-effective. The red SLA-570 provides a luminous intensity of up to 2400 mcd at 20 mA, and the green lamp emits up to 750 mcd at the highest ranking, both with a 24° viewing angle. Device mean time between failures is put at 100,000 hours. Forward voltage for the red GaP LED is 1.75 V and power dissipation is 100 mW; for the green GaAlAs LED the equivalent specifications are 2.3 V and 75 mW.

For More Information Write In No. 820

Nanometer Technologies, San Clarita, CA, introduces a 1300-nm ultralow-back-reflection **variable attenuator** that is available with FC, ST, and APC-type connectors. The Model 2020's maximum back-reflection with an APC connector is less than -65 dB. Attenuation range is 35 dB. The attenuator costs $450 with standard FC connector.

For More Information Write In No. 821

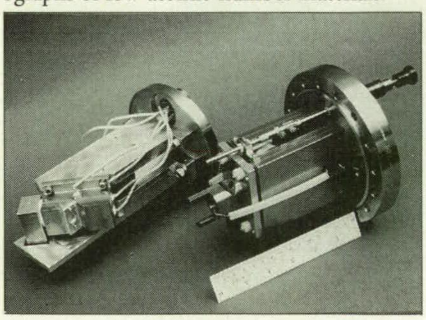
SensorPhysics, Carmel, CA, introduces a real-time **laser beam profiler**. The LaserTest Ultra's PC video display boards combine super VGA graphics with video frame-grabbing, permitting 640 X 480 by 256 color images to be acquired at 30-Hz video rates. Adding memory directly to the video card enables sequential images to be acquired from CW or pulsed lasers with the LaserTest Movie module.

For More Information Write In No. 817

The new Surveyor 3500 noncontact **laser digitizing system** from Laser Design, Minneapolis, MN, has up to six axes of rotation. The effective work envelope is 30" X 30" X 24" and overall volumetric performance accuracy is 0.002". The 5-axis head enables scanning of sidewall information, and a rotary stage allows for a full 360° scan of the part.

For More Information Write In No. 818

X-ray and Specialty Instruments, Ann Arbor, MI, announces a high-output multianode inspection and calibration **soft x-ray source** called Xcalibr. Useful for calibrating x-ray films, crystals, diodes, proportional counters, and transmission of thin films, the source's multiple access ports and electronic chopping enable real-time flux monitoring and absolute cross-calibration of detectors. In-situ selection of sixteen different anode materials and filters makes possible high-contrast radiographs of low-atomic-number materials.

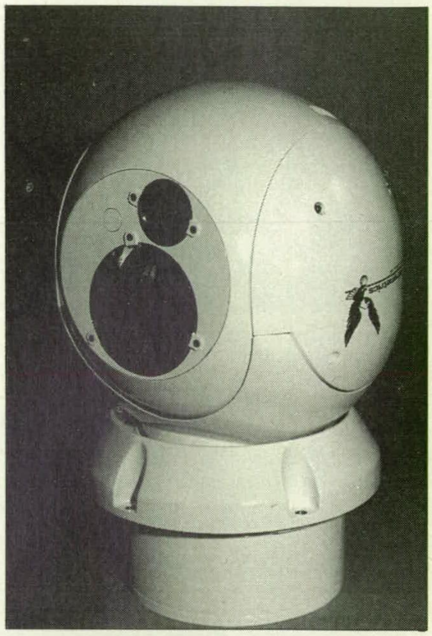


For More Information Write In No. 822

Oriel Corp., Stratford, CT, offers a new line: HgCdZnTe **infrared detectors** with a broad spectral response, up to 2 to >12 µm for some models. Detectivity is >1 X 10^{11} cm $Hz^{0.5}$/W at 3.5 µm for a TE-cooled model. Offered mounted or unmounted, the detectors can be used directly with an oscilloscope for CO_2 laser measurement and IR gas analysis, and with a host of other IR detection instruments.

For More Information Write In No. 826

From Inframetrics, No. Billerica, MA, comes the new Model 445G-MKII gimbal **IR imaging system**. The dual-sensor portable system, designed for fixed-wing and rotary aircraft, features both IR and color CCD TV cameras. The MKII, a 9-in.-diameter ruggedized and environmentally sealed sphere, weighs less than 29 lbs.



For More Information Write In No. 823

Exergen Corp., Newton, MA, makes available a new low-cost noncontact **infrared sensor**. The IRt/cTM.10 thermocouple can measure the temperature of a 1-in. spot from 10 inches distant. The sensor is easily wired to all standard thermocouple controllers, PCs, transmitters, and other devices because no power is required. Exergen IRt/c prices begin at $199.

For More Information Write In No. 831

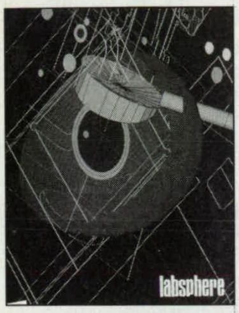
The S4402 from Hamamatsu Corp., Bridgewater, NJ, is a **silicon avalanche photodiode** with a 1-mm active area divided into four equal sections. It has a spectral response of 400-1000 nm; peak-sensitivity wavelength is 800 nm. Quantum efficiency is 75 percent at peak, and dark current is typically 0.8 nA. It will operate from -20 to +60 °C.

For More Information Write In No. 829

The pigtailed InGaAs **PIN photodiode** model ETX 75FITL-A-FJM from Epitaxx, West Trenton, NJ, is designed for digital fiber-in-the-loop receiver applications. Typical specifications are 0.8 A/W responsivity (1300 nm) and 0.6 pF capacitance. The company says these values derive from a proprietary technique for coupling fiber to a sensor with a 75-µm active diameter. In a coaxial package, the photodiode is pigtailed with a 50/125-µm multimode 900-µm-jacketed fiber that can be terminated with FC, ST, SC, or other standard connector.

For More Information Write In No. 832

NEW LITERATURE



The full-color 154-page **1994-95 catalog** from Labsphere, North Sutton, NH, outlines its complete range of laboratory instruments, components, and services. Described are the line of standard integrating spheres from 1-76″ dia. for the UV, VIS, and IR, and the capability in OEM custom integrating spheres. Other sections are devoted to uniform source systems, photometric and radiometric systems, and reflectance/transmittance systems, and to reflectance standards and diffuse reflectance coatings. Featured is Spectralon, a proprietary material Labsphere says has the highest diffuse reflectance of any known material. The company can fabricate laser cavities, line scanners, panel reflectors, backlight illuminators, and more from the material.

For More Information Write In 700

Instruments S.A., Edison, NJ, has a new **"Guide to Spectroscopy"**, a reference for optimization that proceeds stepwise from light source through coupling optics and spectrometer to detector. Sections advising on how to improve optical throughput and detection technique are provided, complemented by detailed information about Jobin-Yvon and SPEX spectrometers, light sources, sampling accessories, detectors, controllers, and software.

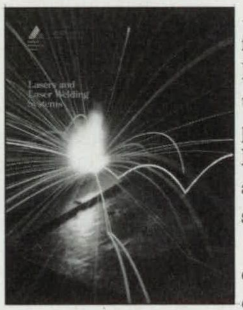
For More Information Write In 701

The four-page full-color brochure from LightHouse Digital Systems, Grass Valley, CA, describes its lines of high-speed **digital switchers and fiber optic products** for coaxial and fiber digital video, audio, and data communications. They include the DCR, called by the company a cost-effective 300-Mb utility switcher; the SRX, a 400-Mb coax/fiber switcher; and the Pathfinder, a 400-Mb-to-1.5-Gb coax, fiber, or fiber/coax combination switcher. Prices range from $1325 (DCR) to $7250 (Pathfinder) for standard models.

For More Information Write In 702

Princeton Instruments, Trenton, NJ, offers a series of application notes dealing with the **technology and operation of CCD cameras.** Application Note 1 treats "Slow CCD Cameras: Who Needs Them & Why;" No. 2, "Slow ICCD Cameras: Who Needs Them & Why;" No. 3, "Lens Coupled vs. Fiber Coupled ICCDs;" and No. 4, "Cooled CCD Cameras for Low Light Imaging: Product Line Overview." The company markets a varied line of CCD and intensified CCD detectors for spectroscopy and gated imaging, as well as x-ray detectors, camera controllers, and image processing software.

For More Information Write In 703

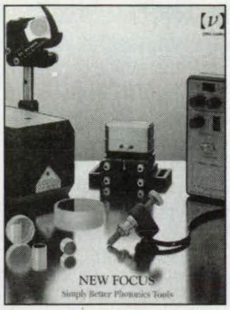


A new brochure from Benchmark Industries, Goffstown, NH, incorporates their line of **Nd: YAG lasers and laser welding systems.** Six of the 12 full-color pages describe the technical features and specifications of the systems; optional items that can be custom-designed to requirements are also detailed. This is Benchmark's first brochure dedicated to the expanded line of lasers and laser systems since the acquisition of the assets of Raytheon's Laser Products Division.

For More Information Write In 704

Selcom Electronic, Southfield, MI, has prepared a 12-page full-color capabilities brochure and reference list summarizing the applications of more than 4,000 fixed-beam Optocator **noncontact dimensional gauging sensors** the company has on-line around the world. Industries using them include rubber, steel, foundry, aluminum, food, packaging, highway, wood, robotic welding, and many others.

For More Information Write In 705

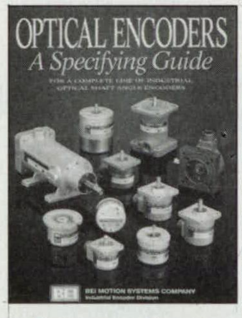


New Focus, Sunnyvale, CA, releases its 76-page **1994 catalog.** It offers details on the broad range of the company's product lines and technical assistance services. Included are information on its external-cavity continuously tunable diode laser, its photodetectors and receivers, modulators and integrated-optic devices, motorized and vacuum-compatible miniature optical mounts, multiaxis stages and fiber aligners, mirrors, waveplates, polarizers, and more. The full-color volume includes diagrams, technical background, product specifications, and prices.

For More Information Write In 706

Sine Patterns, Penfield, NY, makes available a catalog of sinusoidal test **pattern arrays** and single-frequency patterns. Applications include MTF evaluation of materials, lenses, devices, and systems. Single-frequency patterns have also been used extensively for moire contouring. Special orders are welcome. The catalog describes standard arrays and patterns.

For More Information Write In 707



BEI Motion Systems' Industrial Encoder Division, Goleta, CA, has published **"Optical Encoders: a Specifying Guide."** The 20-page 2-color booklet has descriptions and specifications for five series of size 25 through 40 optical shaft angle encoders, including electrical, mechanical, and dimensional information, and waveform patterns and termination details.

For More Information Write In 708

A 70-page catalog from Hamamatsu Corp., Bridgewater, NJ, covers its comprehensive line of "Photomultiplier Tubes and Accessories for Scintillation Counting and High-Energy Physics." It also provides a thorough tutorial discussion of PMT fundamentals, characteristics, and guidelines.

For More Information Write In 709

INDUSTRY LEADERS

Profiles of Pathsetting Companies In The Photonics Field

DAVID RICHARDSON GRATING LABORATORY

OF MILTON ROY COMPANY

The David Richardson Grating Laboratory of Milton Roy Company (formerly part of Bausch and Lomb) is the world's largest supplier of diffraction gratings. We offer a wide selection of ruled and holographic gratings for x-ray, ultraviolet, visible, near-infrared, and infrared applications. The gratings are available in a variety of sizes, blaze angles, and groove frequencies suitable for research instruments as well as OEM applications.

Milton Roy provides expert technical assistance in choosing grating parameters for particular situations, as well as custom grating design and fabrication services. Our expanding line of concave holographic aberration-reduced gratings offers single-element imaging and dispersion. Our wide variety of echelle gratings offers solutions to applications requiring very high spectral resolution, and are well suited to many CCD formats.

Many different fields, such as pulse compression, laser tuning, spectrometry, and astronomy, make use of the gratings made by Milton Roy. We have a large body of data relating to efficiency, stray light, imaging, and other grating characteristics, painstakingly developed over the past 40 years.

Our state-of-the-art ruling engines have been continuously improved and upgraded as new technology became available, so as to provide gratings that exhibit the highest possible efficiency while achieving stray-light characteristics approaching those of holographic gratings.

We are dedicated to providing you with the best solution to your grating needs. Please call or write to discuss grating-related issues, or obtain our new *Grating Catalog.* In addition, we have a newly updated *Grating Handbook* which describes how gratings behave and techniques to choose the best one for your particular requirements.

Contact: Robert Callens, David Richardson Grating Laboratory, Milton Roy Company, 820 Linden Avenue, Rochester, NY 14625. Tel: 800-654-9955 or 716-262-1331. Fax: 716-248-4081.

PRINCETON INSTRUMENTS, INC.

EXCELLENCE IN ENGINEERING AND DESIGN

Princeton Instruments uses the latest in computer-aided design to engineer the highest-performance camera systems possible. We are continually pushing the state of the art in many different areas to offer our customers the best camera technology in every discipline. Thus we work constantly to improve not only our low-noise electronics, but also the mechanical, optical, and software engineering required to build high-performance cameras.

We work with every major manufacturer of CCD arrays and image intensifiers in the world. When they have not been able to provide the necessary performance, we have even designed custom CCD arrays for specific applications. PI is dedicated to the state of the art and is committed to improving performance in every major category.

From early in the company's history, Princeton Instruments has offered complete detection systems for many different types of applications. This includes not only a complete line of hardware systems and accessories, but complete software packages as well. To simplify system installation, PI has either manufactured or arranged for the manufacture of the appropriate optical or mechanical systems.

Contact: Alfred Mottola, Princeton Instruments, Inc., 3660 Quakerbridge Rd., Trenton, NJ 08619. Tel: 609-587-9797; Fax: 609-587-1970.

EG&G ELECTRO-OPTICS

IN-DEPTH EXPERIENCE WITH A LONG HISTORY

Based in Salem, Massachusetts, EG&G Electro-Optics is part of the EG&G Optoelectronics Group. The company's roots extend to 1931, when Dr. Harold (Doc) Edgerton and Kenneth Germeshausen, while working at the Massachusetts Institute of Technology, developed the first stroboscopic techniques to analyze synchronous motors. It was the beginning of "stop motion" study, and later became the basis for the first patent on stroboscopes. When Herbert Grier, also of MIT, joined Edgerton and Germeshausen, the EG&G partnership began and subsequently EG&G Inc. was formed in 1947.

Contact: Ray Radford, EG&G Electro-Optics, 35 Congress Street, Salem, MA 01970. Tel: 508-745-3200; Fax: 508-745-0894.

The Electro-Optics Division was part of the original EG&G operation and the first to produce commercial products for industry. Many products made today trace their origins to the basic xenon flashlamp designs and various pulse circuit inventions of the company's three founders. From early use in stroboscopes, EG&G pulsed xenon systems are now employed in a diverse set of applications including photocopy, clinical and analytical chemistry, beaconry, solid-state and dye lasers, and machine vision.

EG&G Electro-Optics is a leading supplier and innovator of products for scientific instruments, with a history that includes high-quality flashlamps, trigger circuitry, and systems for ultraviolet-visible and near-infrared spectroscopy. The company recently introduced a new line of high-stability short-arc xenon flashlamps and power supply components designated the 1100 Series™. The lamps are constructed with improved electrode materials, optimized fill-gas pressures and mixes, and a choice of packages and windows for selected spectral output characteristics.

This EG&G division is perhaps best known for its in-depth experience with integrating pulsed xenon light source technology into the total illumination and detector systems of OEMs. These efforts range from basic R&D and prototype development to dedicated full-scale production and testing.

EG&G INSTRUMENTS

A GLOBAL SUPPLIER OF ANALYTICAL INSTRUMENTATION

The Scientific Instruments Division of EG&G Instruments is a global supplier of instrumentation and analytical systems to the research and industrial market. In addition to the USA offices, the organization incorporates direct sales and service facilities in most major European countries and has representatives in many other areas of the world.

Its products and systems are manufactured to ISO 9000 standards in world-class production facilities based in Europe and in the USA.

The major products include optical multichannel analyzers, research and industrial Raman spectrometers, light measurement systems based on calibrated traceable standards, fiber optics quality control instrumentation, and signal recovery modules.

Contact: Patricia Murphy, EG&G Instruments, P.O. Box 2565, Princeton, NJ 08543-2565. Tel: 609-530-1000; Fax: 609-883-7259.

Typical applications include nondestructive testing of materials, surface analysis, detection and recovery of signals obscured by electronic noise, and optical measurement of radiation, reflection, and transmission in spectroscopic analysis and quality control.

EG&G Instruments is a group within EG&G Inc., a Fortune 200 company with annual sales of $2.7 billion. EG&G provides systems engineering, precision component manufacturing, and test-site operating and management services to many government agencies and laboratories, and employs 35,000 people worldwide.

EG&G RETICON

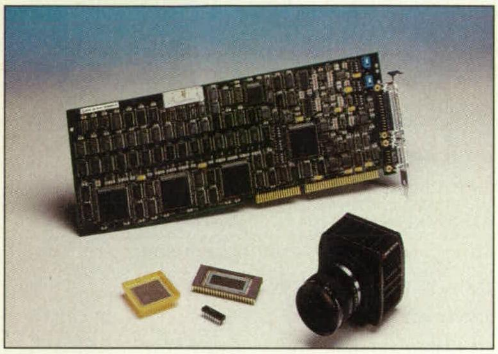
A WORLD LEADER IN IMAGING AND CAMERAS

EG&G Reticon, based in Sunnyvale, CA, is part of the EG&G Optoelectronics Group and specializes in the design and manufacture of high-performance photodiode arrays, charge-coupled device (CCD) imagers, and cameras based on these technologies. Parent EG&G Inc., headquartered in Wellesley, MA, is a diversified Fortune 200 company with over 35,000 employees.

EG&G Reticon offers the broadest line of detectors and cameras of any manufacturer in the world, supporting a broad range of applications including spectroscopy, astronomy, ranging and gauging, document scanning, medical imaging, and industrial imaging. EG&G Reticon also specializes in the design and manufacture of custom imaging components, imaging multiplexers, and cameras for defense, aerospace, and industrial applications. Space-qualified Reticon arrays have flown on missions such as NASA's Voyager spacecraft and many European Space Agency satellites.

EG&G Reticon is regarded as one of the world's leaders in technology and capability. Our high-speed imaging devices and cameras, which cover the near-UV to the near-IR spectral range, feature low noise, wide dynamic range, and high resolution. We also feature optically flat, large-area backside-thinned CCDs to 2k X 2k for high-resolution low-light imaging applications. We offer ceramic and metal packaging and can integrate a thermoelectric cooler directly into the package of any of our arrays. Our windowing options include quartz, sapphire, glass, a linear-variable filter, fiber optic, and unwindowed.

EG&G Reticon's facilities include an in-house wafer fabrication shop, incorporating Class 100 and 1000 clean rooms, complete design and simulation capabilities, and optical test laboratories, along with state-of-the-art automated production testers. All is supported by a team of highly qualified scientists, engineers, and technicians with experience in silicon semiconductor imaging technologies.



Contact: Jody Small, EG&G Reticon, 345 Potrero Ave., Sunnyvale, CA 94086. Tel: 408-738-4266; Fax: 408-738-6979.

SUMMERS OPTICAL

DIVISION OF EMS ACQUISITION CORP.

Based in Fort Washington, Pennsylvania, Summers Optical (formerly Summers Laboratories, Inc.) was one of two companies originally selected by the military in 1956 to produce the industry's first synthetic optical adhesive.

Since then Summers has expanded their cement line to include 2-component and UV-curing optical cements. In fact, they introduced the first UV-curing optical cement in 1965. All of their cements are based on Military Specification MIL-A-3920 and have been used in the US space program since the Mercury flights.

Today their line includes a Glass-To-Metal Adhesive System manufactured to Military Specification MIL-A-48611 and a kit to test the adhesion and abrasion resistance of optical coatings as per all Military Specifications.

Researching solutions to the cementing needs of the optical industry has been a major activity at their facility, and engineers and technicians worldwide have come to depend on the advice and products of Summers Optical for the solutions to their cementing applications.

Lens Bond Optical Products solve problems in broad transmission, high shock and chemical resistance, differences in thermal expansion, laser and filter applications, as well as the bonding of glass to metal, glass to crystal, and glass to plastic.

Precision optical producers throughout the world have banked on the consistently dependable quality of Lens Bond Optical Cements for nearly 40 years.

Contact: Stacie Kirsch, Summers Optical, 321 Morris Road, PO Box 162, Fort Washington, PA 19034. Tel: 215-646-1477; Fax: 215-646-8931.

OMNICHROME

LEADERS IN HeCd, Ar ION, AND Kr ION LASERS & SYSTEMS

Year after year, Omnichrome remains the leading manufacturer of the highest-quality air-cooled lasers and laser systems available today. Being the first choice for original equipment manufacturers including research and development laboratories, academic institutions, governmental agency laboratories, and international businesses, Omnichrome's products fulfill the highest expectations for performance in meeting custom mechanical, electrical, and optical configurations.

Omnichrome's products prevail in markets including lasers for high-volume electronic printing, stereolithography, CD and submicron mastering; lasers for medicine, biology, and chemistry, including flow cytometry, DNA sequencing, confocal scan microscopy, electrophoresis, chromatography, and more; lasers for nondestructive testing, including wafer CD measurements and surface inspection, PWB inspection, Doppler anemometry, particle counting, and more; lasers for forensic examination systems, lasers for entertainment and display, and lasers for research and development in almost every science.

Omnichrome was founded in 1981 and currently occupies a 55,000-square-foot corporate headquarters, engineering, and manufacturing facility. In addition, a worldwide sales and service network ensures an immediate response to all your laser needs.

Contact: Ray Ried, Omnichrome, 13580 Fifth St., Chino, CA 91710. Tel: 909-627-1594; Toll Free: 1-800-525-OMNI; Fax: 909-591-8340.

Call Omnichrome today and speak to one of our knowledgeable laser product specialists. For applications listed here and many others, Omnichrome is the undisputed leader in air-cooled, electro-optical laser systems.

TINSLEY LABORATORIES

THE ASPHERE COMPANY

When the Space Shuttle Endeavour carried up its payload of three to four tons of hardware for the Hubble Space Telescope, it was the most ambitious servicing operation ever to be attempted by NASA.

A very small but critical package in the shuttle's cargo, however, weighed only eight ounces. This was the series of special optics, manufactured by Tinsley Laboratories of Richmond, CA, on which so much of the mission's success depended.

To clear up Hubble's blurred vision, the company produced two series of the required corrective optics. One set is incorporated in Hubble's main photographic instrument, the observatory's new Wide Field/Planetary Camera II, which replaced and substantially upgraded Hubble's existing WF/PC I. The mirrors in WF/PC II, manufactured by Tinsley for the Jet Propulsion Laboratory in Pasadena, were designed to cancel out the focusing error in the telescope's primary mirror.

The second set is an optical chain of ten mirrors, no larger in diameter than dimes or quarters, configured to intercept and correct light rays from Hubble's primary mirror and then direct them to the observatory's three other instruments. These are the Faint Object Camera, Faint Object Spectrograph, and the Goddard Space High-Resolution Spectrograph. Fabricated by Tinsley for Ball Aerospace Systems Group of Boulder, CO, the mirrors are an integral part of COSTAR (Corrective Optics Space Telescope Axial Replacement), a telephone-booth-sized module that Endeavour's astronauts installed in Hubble's main bay. James Crocker of the Space Telescope Science Institute, the leader of the COSTAR team, says that, "To their credit Tinsley Laboratories produced all of the COSTAR optics on time, within budget, and exceeding all of the requirements."

Contact: Robert J. Aronno, Tinsley Laboratories, Inc., 3900 Lakeside Drive., Richmond, CA 94806. Tel: 510-222-8110; Fax: 510-223-4534.

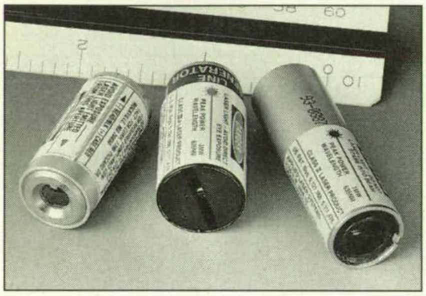
"We were very proud to have been associated with NASA, the Jet Propulsion Laboratory, and the Ball Aerospace Group on this historic repair mission," says Robert J. Aronno, President of Tinsley. "We salute them for their work in meticulously designing and aligning the mirrors, and the Endeavour astronauts for so brilliantly carrying out the mission."

Founded in 1926, Tinsley Laboratories is the leading independent company in the precision optics industry specializing in the design and fabrication of aspherical optical surfaces. Tinsley's discrete lenses and mirrors and the company's optical assemblies are used in precision optical and electro-optic systems with space, military, scientific, and industrial applications. Through its subsidiary, Century Precision Optics of North Hollywood, CA, Tinsley also makes specialty lenses and accessories for the film and video industries.

APPLIED LASER SYSTEMS

WORLD'S LARGEST MANUFACTURER OF LASER DIODE PRODUCTS

Since 1988, Applied Laser Systems (ALS) has specialized in the design and manufacture of high reliability, high performance, electro-optical and semiconductor laser products. Our innovative product design, precision manufacturing techniques, and total quality control systems combine to meet the most demanding needs of our customers. At our manufacturing plant, located in Grants Pass, Oregon, we have assembled a dedicated and highly qualified team of managerial and technical staff where we endeavor to introduce cost-effective products, and utilize our scientific engineering, process and design efficiency to react quickly to the needs of our customers.



Contact: Lisa Brennan, Applied Laser Systems, 2160 N.W. Vine Street, Grants Pass, OR 97526. Tel: 503-479-0484; Fax: 503-476-5105.

ALS creates innovative products that allow product designers and R&D engineers to bypass the frustrating and expensive process of trying to stabilize the raw laser diode by simply "plugging" the patented ALS Visible Laser Module (VLM™) directly into an application. The VLM™ product is the most advanced laser module system on the market today. Our miniature design incorporates the laser diode, drive circuits and sophisticated optics into one tiny, self-contained, shock-resistant package, allowing us to maximize power efficiency while protecting the internal circuitry from electrostatic discharge, spiking overload and reverse polarity. In short, the VLM™ product makes the fragile laser diode virtually indestructible.

Available in 830 nm-635 nm wavelength and power outputs from 1 mW to 50 mW, the ALS VLM™2 product line is well suited for pointing, locating, scanning, point-to-point voice, data, video communications, timing, and other applications. Reliability, ruggedness, and efficiency are all built into ALS visible modules. The complete unit houses the lens, laser diode, electronics, and green LED indicator.

ALS now has available an Industrial Power Box for use with Industrial Housed VLM™2 series. This rugged power box enables you to plug up to six Industrial Housed VLM™2 into one power source. It is available in both 100V and 220V.

Integrity in our business dealings, quality and reliability in our products, and responsiveness to our customers' needs are the corporate values by which ALS acts.

Advertisers Index

Exclusive!

Russia's Top Technologies Unveiled For The First Time

The Cold War is history and Russia's open for business, offering a treasure-trove of previously classified inventions to U.S. companies. You can find the best, most commercially-promising Russian technologies—ahead of the crowd—with ***Russian Tech Briefs,*** the official technology transfer publication of the Russian Space Agency.

This new bimonthly newsletter from the publisher of *NASA Tech Briefs* features new product ideas, licensable inventions, and novel engineering solutions in materials science, biotechnology, electronics, computing, environmental technology, manufacturing, and more. Using the Reader Service Form in each issue, you can order more detailed technical and licensing information on particular articles.


RUSSIAN
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Welcome To The Premiere Edition Of *Russian Tech Briefs,*
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LITERATURE SPOTLIGHT

Free catalogs and literature for Laser Tech Briefs' readers. To order, write in the corresponding number on the Reader Information Request Form (page 51).

WORLD'S BEST SPHEROMETERS

Super-Spherotronic features NBS traceable, calibration level accuracy combined with automated operation and the ease of use needed for production and QC. The Ultra-Precise probe is accurate to ±0.2 µm, radius of curvature is accurate to 0.01%. Spherocompact is a digital, hand-held unit featuring a Micron resolution, linear encoder. It measures in mm or inches. RS-232 interface is standard.

Mildex Inc.

For More Information Write In No. 300

OPTICAL FILTERS CATALOG

ARC's VUV-UV-VIS-NIR Optical Filters catalog features filters for the wavelength region extending from the Near-IR (1064 nm) to soft x-rays. Included are narrow and broadband UV filters, neutral density filters, reflective filters, bandpass filters, cut-off filters and UV filter glass.

Acton Research Corporation

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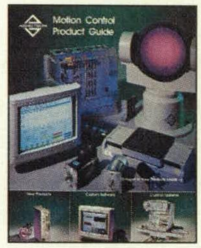
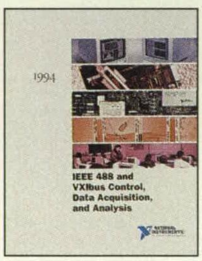


NEW MOTION CONTROL PRODUCT GUIDE

Aerotech's new 248-page Motion Control Product Guide provides in-depth technical data and design information for our linear and rotary positioning stages; microstepping motors and translators, servo motors and drivers (both DC and brushless); position transducers; and motion controllers (from one to 16 axes). Aerotech, Inc. 101 Zeta Drive, Pittsburgh, PA 15328. Tel: 412-963-7470; Fax: 412-963-7459.

Aerotech

For More Information Write In No. 302



COMPUTER-BASED INSTRUMENTATION

Free 1994 catalog of hardware and software for computer-based instrumentation. Features software for Windows, Windows NT, Macintosh, UNIX, and DOS, including LabVIEW, LabWindows, and the new LabWindows/CVI. Describes IEEE 488.2 interfaces, plug-in data acquisition boards, VXIbus controllers, and signal conditioning accessories. Customer education classes also detailed. Includes tutorials and glossary.

National Instruments

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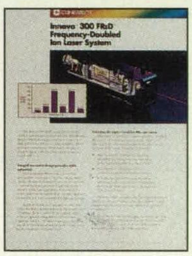
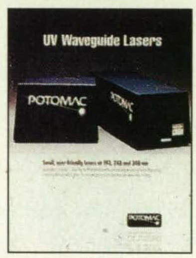


NOW AVAILABLE

Six CW deep UV laser lines between 229 nm and 264 nm and a new brochure that describes the laser system—Coherent's Innova® 300 FReD FREquency Doubled ion laser—which includes power specifications, beam parameters, and laser design characteristics.

Coherent, Inc. Laser Group

For More Information Write In No. 304



UV WAVEGUIDE LASERS

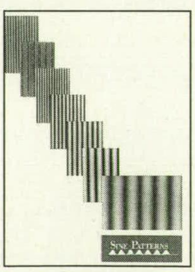
Potomac's compact RF discharge excimer lasers offer unique characteristics including 2000 Hz maximum pulse repetition rate, simplified operation and 110-volt, air-cooled operation. Applications include micromachining of diamond, glass, ceramics, polymers and thin metal films, surface analysis, injection locking, and dye laser pumping. Potomac Photonics, Inc. 4445 Nicole Drive, Lanham, MD 20706. Tel: 301-459-3031. Fax: 301-459-3034.

For More Information Write In No. 305

SUMMERS LABORATORIES has an optical cement or adhesive for all applications, be it military or proprietary, in accordance to military specification or not. The Summers family of cements includes UV Curing, and 2-component adhesives as well as a complete line of cement room supplies, mixing kits, and a Lens Coating Hardness Tester kit to test lens coatings in accordance to various Military Specifications. For a complete catalog or more information on any of our products please call or write today. Summers Laboratories, A Division of EMS Acquisition Corp., Tel: 215-646-1477. Fax: 215-646-8931.

Summers Laboratories

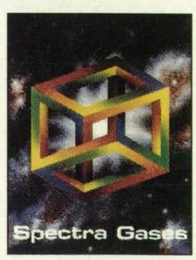
For More Information Write In No. 306



The latest Sine Patterns catalog includes a variety of sinusoidal test patterns made on either photographic film or paper. Applications include MTF evaluation of materials, lenses, scanners, devices, and systems. Single frequency patterns are especially useful for moire contouring. Engineering notes are available. Special orders are welcome. Tel: 716-248-5338 Fax: 716-248-8323

Sine Patterns

For More Information Write In No. 307



SPECIALTY GAS AND EQUIPMENT CATALOG

Free! The 1993 rare and specialty gas and equipment catalog from Spectra Gases of Irvington, NJ, contains specifications on rare gases, excimer laser gas mixtures, halogen gas premixtures, helium-3 and isotopic gases, research gases and mixtures, gas safety cabinets, and automatic and manual gas-handling systems. Krypton and argon ion-laser tube remanufacturing, halogen scrubbers, and "oil-free" vacuum pumps are highlighted.

Spectra Gases

For More Information Write In No. 308

FREE LIGHT RESEARCH CATALOG

Oriel's new Volume II Product Guide: **Light Sources, Monochromators & Detection Systems** is a 528 page technical reference manual and product catalog in one. New, technically advanced products to make, move and measure light include UV to NIR pulsed light sources, nitrogen and tunable dye lasers, calibrated irradiance sources and single and dual beam scanning spectrophotometers. Tel: 203-377-8282. Fax: 203-375-0851.

Oriel Corporation

For More Information Write In No. 334

FAST QUANTITATIVE IMAGING

Send for our 4-page color brochure describing the PXL™ high speed, modular camera system. PXL delivers low-noise and variable frame rates for quantitative imaging. This cooled 12 bit camera is well suited for dynamic and/or low-light applications.Tel: 602-889-9933 Fax: 602-573-1944.

PHOTOMETRICS

For More Information Write In No. 335

DIFFRACTION GRATINGS—

WORLD'S MOST COMPLETE SELECTION

Free—A new *Grating Catalog* describing the complete listing of Milton Roy gratings, and a new *Grating Handbook* providing a thorough overview of grating use and design considerations. Gratings for the spectral range from the x-ray through the infrared are available from the world's largest supplier of diffraction gratings.

Milton Roy Diffraction Gratings

For More Information Write In No. 336

FIBER OPTIC PRODUCTS/ EMITTERS AND DETECTORS

New from EG&G Optoelectronics Canada is a brochure listing emitter and detector components for use in fiber optic systems. Products for high-speed communications include LEDs, silicon and InGaAs PIN photodiodes and receiver modules, and 980 nm lasers for EDFA repeaters. Devices for fiber optic test equipment include pulsed lasers and InGaAs and germanium APDs and OTDRs. EG&G Optoelectronics Canada, 22002 Dumberry Road, Vaudreuil, Quebec J7V 8P7.

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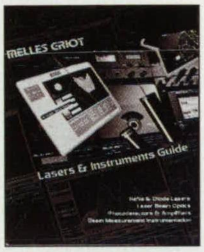


Melles Griot introduces its comprehensive new 356-page **Lasers and Instruments Guide**. Presenting Helium Neon lasers, diode lasers, and an array of laser and photonic instrumentation in one easy-to-use reference volume, it includes a variety of optical lenses, filters, and accessories commonly used with laser products. Tutorial background is provided in the areas of Gaussian beam laser theory, laser wavefront and frequency characteristics, and quantum detector theory.

Melles Griot

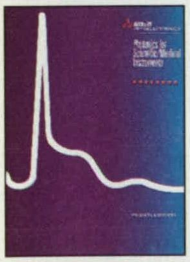
For More Information Write In No. 338

PC IMAGING BOARD

Literature is available for the 4MEG VIDEO Model 12 image capture, processing and display board for the PC. The Model 12 features sampling/display rates up to 50 MHz, 64 Mb of image memory and 50 MHz processor. The Model 12 interfaces to most sources for single or sequential image capture. The literature describes features of the Model 12, along with information regarding software and interface options.

EPIX Inc.

For More Information Write In No. 339

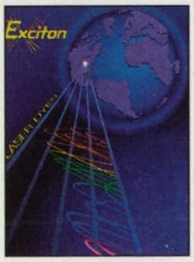


PHOTONICS FOR SCIENTIFIC/MEDICAL INSTRUMENTS

EG&G Optoelectronics has published a new short form catalog and selection guide containing its most popular photonic products for use in analytical instruments and medical applications. This 28 page book is organized by product section, including camera tubes, image sensors, laser diodes, UV-VIS-IR photodiodes, IR emitters and phototransistors, and a wide range of high quality lamps and flashtubes.

EG&G Optoelectronics

For More Information Write In No. 340



LASER DYES

With Exciton, you get a specialized team of professionals knowledgeable in the field of laser dyes. Since more than one dye may cover a given spectral region, we provide the latest information concerning the best dye selection for a specific laser system and application. Exciton Inc., PO Box 31126, Overlook Station, Dayton, OH 45431.

Exciton Inc.

For More Information Write In No. 341

A 100-plus page, full color HIGH PERFORMANCE CAMERAS catalog from Princeton Instruments, Inc., Trenton, NJ, is now released. Slow scan imaging CCD cameras with spectral response from x-ray to the NIR, and with applications from microscopy to astronomy, are outlined. The catalog also provides the specifications for the more thirty different CCD chips offered in Princeton Instruments, Inc. cameras and useful application notes to help in the selection of a camera system.

Princeton Instruments, Inc.

For More Information Write In No. 342

AUXILIARY WORK SURFACE

This specification sheet describes features and applications for the Overhead Shelf Systems. It also contains a list of available sizes and accessories as well as an outline drawing. Kinetic Systems, Inc., Tel: 617-522-8700; Fax: 617-522-6323.

Kinetic Systems, Inc

For More Information Write In No. 343

HIGH POWER SMALL PACKAGE HeCd LASERS

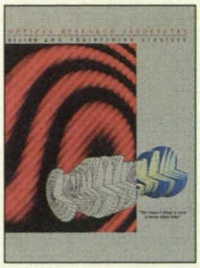
Omnichrome again is the leading innovator in Helium Cadmium Lasers by offering the highest power, smallest package 442 nm, 354 nm, and 325 nm, and Simultaneous Dual Line UV/VIS lasers available. All internal mirror, rugged, standard and custom configuration lasers are built for OEMs demanding reliability yet still ideal for research and scientific applications requiring flexibility. Tel: 909-627-1594, 800-525-OMNI; Fax: 909-591-8340.

Omnichrome

For More Information Write In No. 344

REACH 48,000 LASER/OPTICS PROFESSIONALS DIRECT

Laser Tech Briefs' Action Cards are direct business reply postcards bound into each issue to carry your message to 48,000+ laser, optics, and photonics professionals in industry, government, and the academy. These are technology managers, design engineers, and scientists who will avail themselves of this direct method of obtaining information on your product or service. The Summer 1994 issue is your next opportunity to use this marketing tool. Contact your Laser Tech Briefs sales representative (listed on page 8) or call Joe Pramberger at (212) 490-3999.



ENGINEERING SERVICES

The pre-eminent optical design and engineering firm, Optical Research Associates, provides world-class engineering solutions across the entire spectrum of optical design. From x-ray wavelengths to the far infrared, from optical systems for consumer and industrial products to highly complex government and military applications, ORA leads the way. Optical Research Associates, 550 N. Rosemead Blvd. Pasadena, CA 91107. Tel: 818-795-9101; Fax: 818-795-9102.

Optical Research Associates

For More Information Write In No. 346

LIGHT DETECTORS FOR SPECTROSCOPY AND IMAGING

Our colorful four-page brochure describes our latest Optical Multichannel Analyzer OMA® 4 System, based on the highest quality CCD detectors and signal processing instrumentation available. The brochure provides illustrations of our application-specific software developed for spectroscopy and imaging. Tel: 609-530-1000; Fax: 609-883-7259.

EG&G Instruments

For More Information Write In No. 347

ADVANCED SOLID STATE IMAGE SENSORS

The growing family of solid state image sensors from Kodak are presented in two free brochures: A brief overview of high-resolution CCD image sensors including full frame, interline, linear, and infrared; and a simplified product guide for technical specifications. Tel: 716-722-4385, ext. 260.

Eastman Kodak Company

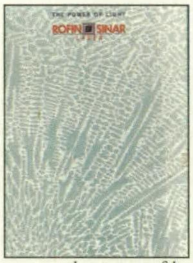
For More Information Write In No. 348

HIGH VOLTAGE POWER SUPPLIES

This catalog from Bertan contains 100 pages of information on solutions to high voltage power supply requirements. Detailed product information on instruments, modules, and NIM power supplies is provided. Standard and custom designs are available for OEM or laboratory applications.

Bertan High Voltage

For More Information Write In No. 349



LASER TECHNOLOGY AND APPLICATIONS

An 18-page brochure available from Rofin Sinar, Inc. provides a concise examination of laser technology and its expanding applications in the manufacturing environment. Detailed are the elements and concepts of lasers critical to modern industry: versatility and flexibility; precision, control, and speed; and the laser's present and potential applications in welding, cutting, drilling, surface treatment, and product identification. Individual sections discuss CO_2 and Nd:YAG lasers, laser marking systems, and Rofin Sinar's capabilities and resources.

Rofin Sinar, Inc.

For More Information Write In No. 350

LASER DIODE OPTICS

A full line of precision optics offered by Optima Precision, Inc., West Linn, Oregon, is for use with laser diode systems including glass & plastic objective and collimating lenses, collimated diode lasers, spherical & cylindrical lenses, beamsplitters, dielectric mirrors, windows, filters, anamorphic, and cube prisms. Applications include alignment, measurement, inspection systems, particle sensors, and bar code readers. Contact Dick Schmitz. Tel: 503-638-2525; Fax: 503-638-4545.

Optima Precision Inc.

For More Information Write In No. 351

MC4013 CCD MATRIX CAMERA

The EG&G Reticon 4013 camera family consists of high-resolution CCD matrix cameras that cover the full range of 1024 x 1024 CCD camera functionality. The 4013 camera series comes in different configurations covering analog and digital outputs with frame rates to 30 fps. The family employs a full-frame 1024 x 1024 pixel CCD sensor that features high dynamic range, low noise, and low current. 345 Potrero Ave., Sunnyvale, CA 94086.

EG&G Optoelectronics — Reticon

For More Information Write In No. 352

For reticles, discs, scales and custom patterns, Gurley Precision Instruments offers broad optographic capabilities in vacuum deposited metal or photographic emulsions on traditional and exotic substrates. Gurley is known for its high accuracy, unusual sizes, and a total in-house capability.

Gurley Precision Instruments

For More Information Write In No. 353

Burleigh Instruments' new Personal SPM series of AFM, STM and UHV/STM systems are designed to make this technology affordable and practical for use in broader areas of application throughout industry and research. Personal SPM systems incorporate innovative technology engineered to reduce the cost of high performance, and with simplified operational features to permit productive use by scientists, engineers, and technicians alike. Burleigh Personal SPM systems are easy to operate and provide high resolution imaging and precise 3D measurement of surface features. Tel: 716-924-9355.

Burleigh Instruments

For More Information Write In No. 354

ADVANCED INTEGRATED DIODE LASERS

A 4-page 4-color brochure describes Visible Laser Module (VLM™) technology, a breakthrough in laser diode miniaturization. Unique design maximizes power coupling while providing enhanced durability. Standard output is visible deep red, but the VLM™ is also available in a variety of power outputs and wavelengths, including IR. New products for 1994 include a 635-nm visible laser module and a 635-nm line generator. Tel: 503-474-6560; Fax: 503-476-5105.

Applied Laser Systems

For More Information Write In No. 355

SYNTHESIZED FUNCTION GENERATOR

The DS345 offers digitally synthesized waveforms to 30 micro-Hz with 1 mHz resolution, arbitrary waveform and modulated outputs. Outputs can be simple sine, triangle, ramp, or square waves; complex arbitrary signals up to 16,300 points can also be created.

Stanford Research Systems Inc.

For More Information Write In No. 356